Basic Research in the Mission Agencies

Agency Perspectives on the Conduct and Support of Basic Research

National Science Board 1978

NATIONAL SCIENCE BOARD

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Report of the
National Science Board
1978

National Science Board
National Science Foundation

LETTER OF TRANSMITTAL

March 24, 1978

My Dear Mr. President:

I have the honor of transmitting to you, and through you to the Congress, the annual report of the National Science Board.

Our tenth report is concerned with the basic research supported by executive branch agencies of the Federal Government. We have been assisted in preparing this survey by detailed submissions from 14 mission agencies and two other agencies that provide important support for basic research.

We hope that this report will serve as a source of information about federally supported basic research for the executive branch, the Congress, the scientific, educational, and business communities, and others concerned with federally supported basic research.

The report includes agency perspectives on how fundamental scientific inquiry assists the Federal Government to carry out its varied missions. The organization and management of this effort, which includes research performers in Government, academia, industry, and the nonprofit sector, also are described.

Respectfully yours,

Norman Hackerman
Chairman, National Science Board

The Honorable
The President of the United States

PREFACE

The National Science Foundation was established in 1950 "To promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense; and other purposes."[1]

The National Science Board, the policymaking body of the Foundation, has as its principal role the discharge of the basic mission ". . . to initiate and support basic scientific research and programs to strengthen scientific research potential and science education programs at all levels. . . ."[2]

The Foundation is also obliged ". . . to evaluate the status and needs of the various sciences as evidenced by programs, projects, and studies undertaken by agencies of the Federal Government. . . ."[3]

The National Science Board believes that the status and health of the scientific enterprise in the United States are good and that our effort compares satisfactorily with that of scientific communities abroad.

The Board's last annual report to the Congress, *Science Indicators—1976,* described the overall U. S. effort. Our pool of scientific personnel continues to be sufficient, in general, to meet the Nation's changing demands and needs. This is due in large part to the strong programs of the so-called "mission agencies" and the others not so classified, which together provide funding for the entire spectrum of science. The vision and support of the legislative and executive branches of the Federal Government have enabled the scientific and educational communities to continue their roles of assisting in the solution of the Nation's problems and improving the quality of life of our citizens.

In 1977 the Congress reinstated in the National Science Foundation Act the requirement that the Board render an annual report to the President for submission to the Congress dealing ". . . essentially, though not necessarily exclusively, with policy issues or matters which affect the Foundation or with which the Board in its official role as the policymaking body of the Foundation is concerned."[4]

For its 1978 report the National Science Board decided to review the contributions of the mission agencies to the Nation's scientific endeavor. As a result of this review of the agencies and their activities, the Board affirms its strong belief in the value of multiple support of scientific research by the Federal Government and in the key role of the mission agencies.

The Board's assessment of the reports of the agencies reveals certain developments, trends, and constraints in the system that should be highlighted for those responsible for research programs as well as for the legislative and executive branches. These are noted in the General Observations and Highlights section of the Overview.

Grover E. Murray, Chairman
Committee on Tenth NSB Report
National Science Board

[1]Public Law 507, 81st Cong.

[2]Ibid.

[3]Ibid.

[4]Public Law 507, 81st Cong., as amended.

FOREWORD

The National Science Board (NSB), the policymaking body of the National Science Foundation (NSF), has among its responsibilities "to evaluate the status and needs of the various sciences . . . and to take into consideration the results of such evaluations in correlating the research and educational programs undertaken or supported by the Foundation with programs, projects, and studies undertaken by agencies of the Federal Government, by individuals, and by public and private research groups."[1] Recent Board reports have dealt with the Nation's total research and development effort and the Federal Government's role in this effort. This tenth Board report focuses on the *basic research* that is supported by the mission agencies of the Federal Government.

The importance and value of basic research to the Nation's total R&D effort has been recognized at the highest levels of Government. The President has said:

> I think to the extent that basic research and development commitments can be oriented towards things that improve the quality of our people's lives and enhance the security of our Nation, contribute to our position in world leadership, to that extent these allocations of funds and interests will be more readily acceptable and supported by the American people.
>
> What we do in science in this country has a tremendous impact on the decisions made in other nations, strong and independent nations, because there is, as you know, a scientific community that is drawn together by mutuality of interest, and that is able to transcend obstacles that are raised by national boundaries.[2]

A recent memorandum from the Office of Management and Budget (see Appendix B) stated that the President

> is particularly concerned with the identification of critical problems currently or potentially faced by the Federal Government where basic or long-term research could assist in carrying out Federal responsibilities more effectively or where such research would provide a better basis for decisionmaking.

The Board has always been concerned about the health of basic research. It expressed this concern publicly most recently in its resolution of October 18, 1974 (see Appendix A):

> Whereas, the national welfare requires and it has been a long standing matter of national policy that mission agencies pursue strong programs of basic research appropriate for their missions;
>
> The National Science Board encourages mission agencies of the Federal Government to maintain strong basic research programs in areas that have the potential of contributing to their mission objectives over the long term.

In pursuit of its own concern and responsibilities concerning the overall Federal basic research effort, the Board has attempted in this report to gather in-

[1]Public Law 507, 81st Cong., 42 U.S.C. 1862 and 42 U.S.C. 1863, as amended.

[2]Remarks, Medal of Science awards ceremony, November 22, 1977.

formation on the basic research supported by the Federal Government and carried out in agency laboratories, universities, industry, and nonprofit institutions.

The objectives of the tenth Board report are:

- To provide an objective survey of the current status of basic research in the mission agencies;
- To serve as a source of information about basic research in mission agencies for Government scientists and administrators, members of the Congress, staff members of congressional committees, members of the scientific, educational, and business communities, and others; and
- To examine historical trends in the support of basic research by the Federal Government.

Most of the basic data for this report comes from information solicited by the Board from Federal agencies involved in science. Fourteen mission agencies and two agencies not so classified and more than 20 subunits of these responded to the Board's invitation to participate.[3] Each agency was given the opportunity to contribute its own submission for inclusion in the report. These appear in Part I.

In addition, the agencies were asked to respond to a series of questions and issues. The questions and issues were stated in an open-ended fashion. (Additional details on the methodology used to obtain agency contributions are included in Appendix C.) To supplement the material provided by the agencies, the Board has drawn upon broader statistical information on Government- and nongovernment-supported R&D regularly collected by NSF. From all this material the Board has constructed an analysis of trends and problems in the support of basic research as it affects research performers and the various fields of science (see Part II).

Finally, in order to give a historical perspective to these trends, the Board has included a summary of the Federal relationship to science since the founding of the Republic (see Part III).

During the past year of preparation of this report, the Board has been impressed with the seriousness with which these Federal agencies have been addressing their long-term responsibilities. There appears to be a growing recognition of the role basic research can play in meeting those responsibilities. It has also been impressed by the breadth and scope of the research and development network that has been built—largely since the conclusion of World War II—a network that utilizes a unique combination of governmental, academic, industrial, and nonprofit resources. Finally, this report provides evidence that, despite a host of recognized problems, federally supported basic research has produced and is continuing to produce significant additions to scientific knowledge.

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[3]Mission agencies are generally defined as those with continuing specific functional responsibilities (e.g., Department of Labor). The National Science Foundation and the Smithsonian Institution, not generally regarded as mission agencies, were included for completeness and comparison purposes.

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OVERVIEW

General Observations and Highlights

Perhaps the broadest generalization that can be made is that agencies have difficulty making a sharp distinction between basic and applied research. The great variation in reporting of research by basic, applied, and other categories can lead to serious discrepancies in Government-wide data on research and development. Given this and other limitations stated below, it is still possible, based on the inputs from the mission agencies, to make some general observations on accomplishments, trends, problems, and issues concerning basic research supported by the Federal Government.[1] These are, in brief:

1. *Basic research is useful.*
   - Federally supported basic research has produced and continues to produce significant additions to scientific knowledge that are or promise to be of high potential in addressing national problems and concerns. Moreover, mission agencies, in the main, acknowledge payoffs from their investments in basic research. Examples of interesting payoffs are listed below in the section "Examples of Basic Research."

2. *Federal support of basic research has declined in constant dollars over the last 10 years.*
   - In current dollars, Federal basic research obligations have grown by an average of 4.3 percent annually from 1968 to 1976 but have declined by 1.8 percent annually in constant dollars. Although there has been a significant upward trend since 1975, estimated basic research obligations for 1978, as shown in the President's budget, are 5 percent lower in constant dollars than 1968 obligations.

3. *Mission agencies have expressed certain concerns about the funding of basic research.*
   - The chief agency concerns have to do with (1) sharp yearly fluctuations in budget authority and (2) legislative expansion of agency responsibilities without commensurate increases in funding. The latter unintentionally can lead to reductions in basic research funding to meet operational or other requirements.

     Several agencies (including the National Bureau of Standards (NBS), the United States Geological Survey (USGS), and the National Oceanic and Atmospheric Administration (NOAA)) point out that funding for research has not kept pace with their increased responsibilities. NBS notes that a large number of tasks have been mandated by the Congress in 15 laws passed since 1965, frequently with no funds appropriated to carry them out. USGS lists 13 pieces of legislation in the last 9 years that have increased its responsibilities without providing increased resources with which to meet them.
   - Limited funding and unpredictability of funding are viewed as primary barriers to the conduct and support of basic research.
   - Major agency concerns about research in universities relate to the quality and adequacy of science manpower supply; instability of funding; increasing red tape in recordkeeping and reporting; and shifts from basic to applied research, from long- to short-term projects, and from high- to low-risk projects.

4. *A number of factors have affected the emphasis on and conduct of basic research.*
   - Certain legislation, specifically the Mansfield amendment, appears to have caused some agencies to deemphasize basic research.
   - General legislation cited as affecting performers of agency-supported basic research includes laws dealing with safety, civil rights, protection of the environment, and preservation of endangered species. Specific acts of legislation and regulations required by legislation affecting the conduct of basic research include those relating to use of experimental animals and human subjects, protection of privacy, research on the human fetus, and use of dangerous drugs.
   - A proliferation of bureaucratic regulations, some of them resulting from the series of social and health laws passed by the Congress, requires agencies to place what seem to be serious hindrances on performers of federally funded research.

One agency finds that Government regulations regarding the control, design, and use of survey questionnaires and protocol pose serious barriers

[1] For a description of the methodology used in preparing this report, see the Foreword and Appendix C.

to the conduct of effective social science research. An official of the agency states:

> These regulations, when taken together with the current government-wide drive to reduce paperwork burdens on the public and private industry, are so onerous as to be an effective barrier to the performance of many social-science research projects. Surveys of a properly drawn sample population are, in fact, among the most effective means of reducing paperwork burdens, when contrasted with typical government requests for information from an entire population.

5. *There has been a considerable increase in basic research in universities and not nearly so much in industry.*
   - Performance of basic research by universities increased 25 fold (in current dollars) during the period 1953-1977; during the same period, performance of basic research by industry increased only 5 fold.
   - Federal support of basic research in universities totaled $1,290 million (current dollars) in 1977. This amounted to 47 percent of total Federal obligations for basic research ($2,755 million) in 1977.
   - Conduct of basic research by industry reached a peak of over $800 million (constant 1972 dollars) in 1966; it has been declining since then, reaching a level of about $550 million (constant 1972 dollars) for the period 1975-1977.
   - Federal support of basic research in industry totaled $201 million (current dollars) in 1977. This represented 7.3 percent of total Federal obligations for basic research ($2,755 million) in 1977.

6. *The changes in funding of basic research by the Federal Government have varied considerably among the fields of science.*
   - Significant increases (in current dollars) occurred in the 1968-1977 period in Federal support of basic research in the life sciences (73.9 percent), environmental sciences (98.0 percent), engineering (71.8 percent), and social sciences (67.2 percent). Support of basic research increased 34.6 percent in the physical sciences and 17.9 percent in mathematics and computer sciences. Support for psychology, treated as a field separate from both the life and social sciences, decreased by 3.6 percent in this period.

7. *There are several approaches to the management of basic research and, as might be expected, there are many problems in the management of basic research.*
   - The factor affecting the quality of basic research projects that was cited most frequently and considered most important was the vision and leadership of the senior officials who plan and direct the work.
   - Unique management services are provided by university consortia. Such management and governing services, which have personnel who understand basic research and which can call upon the most capable scientists to help plan and direct the programs in the laboratories, are considered a valuable national asset.
   - Many officials believe that clarification of the use of the procurement contract, assistance contract, cooperative agreement, and grant would reduce confusion in the research community.
   - Constraints of Civil Service regulations also hinder the management of research in some agencies.

8. *Agency perceptions of "coordination" include connotations of collaboration, correlation, and evaluation. Some agencies are apprehensive about efforts at coordination that might introduce elements of external direction or control.*
   - On the whole, there appears to be a surprising degree of coordination, especially with respect to support and conduct of basic and applied research. This coordination is achieved by both formal and informal means, the latter being particularly important.

9. *Most agencies, in listing priorities and gap areas in their research agendas, frequently mention the need for basic research in the traditional scientific disciplines.*
   - Thus it is not surprising to see the same disciplines occurring in the priority lists of a number of agencies. Eight or more agencies designate subfields of the materials sciences, the environmental sciences, food and nutrition research, physics, chemistry, mathematical and computer sciences, and the life sciences as deserving greater attention.

Problems and Issues

Many agencies identified specific problems and issues facing the scientific community that may need increased attention. The following quotations from agency submissions are illustrative.

- **Agriculture:** . . . A complete understanding of the nature of bacterial resistance to anti-

microbial drugs is essential for the protection of animals and human health.

. . . The study (of requirements of preteenage girls for specific nutrients) also provided evidence that the present National Research Council's recommended daily allowances for protein for children are minimal and do not contain a sufficient margin of safety.

. . . Knowledge of the precise kinds, quantities and balance of nutrients required for human health and productivity is seriously lacking. . . .

- **Alcohol, Drug Abuse, and Mental Health Administration:** . . . There is a need to do careful simultaneous studies of the endocrine and bodily changes of puberty, along with concomitant emotional and behavioral changes. The need for such research is pointed up by the almost absolute lack of reliable information on early adolescent development. Ages 10-15 are not even included as a separate category in the U.S. vital statistics data; this gap in reported data also contributes significantly to the absence of an epidemiology of mental illness in the early adolescent phase.
- **Army:** . . . More than 65 percent of advanced weapons system failures are materials failures.
- **National Institutes of Health:** . . . Another area in which recombinant DNA technology offers hope of important progress is in cloning modified cells for the large-scale production of biological compounds for the treatment and control of disease. . . . Other possible applications of recombinant DNA research include studies to increase plant food production by enhancing the efficiency of photosynthesis, and studies to decrease the fertilizer requirements of crops by transferring directly to plants the microbial enzyme systems that perform nitrogen fixation .
- **Housing and Urban Development:** . . . Many of the phenomena around which HUD must shape its programs are not yet well understood. . . .(A)nalysis has begun to show that some community problems may have counterintuitive solutions, which ordinary experience and common sense might not have suggested.
- **Energy Research and Development Administration:** . . . The industrial firms carrying out ERDA-funded development and demonstration projects typically neither have nor seek funding for basic research tasks. The interactions are mostly quite indirect. The mechanisms for assuring the most fruitful level of interaction need strengthening.
- **National Bureau of Standards:** . . . The fundamental issue regarding basic research in the Government laboratories is the need to maintain a Federal policy that encourages basic research of high quality.

Examples of Basic Research

Through their conduct and support of basic research, the mission agencies have made significant contributions to the progress of science and to the achievement of national goals. For example, basic research is responsible for significant discoveries in the amelioration and cure of disease, conservation of natural resources, support of national defense, promotion of economic growth, and exploration of space. More often than not, years must pass before the full significance of a research result is appreciated. Thus, it may be some time until science and society reap the full benefits of the research being conducted by the mission agencies today.

Hundreds of examples of basic research conducted and/or supported by the agencies are summarized in Part I of this report. The following examples of recent and current basic research are only illustrative.[2]

- *Vaccines for Control of Animal Diseases* (Agriculture): . . . Significant breakthroughs include the development of a vaccine for Marek's disease, a cancer-causing disease in chickens. This has been an outstanding achievement in the field of virus-in-cancer and has reduced large economic losses due to this disease by a dramatic 80 percent. Another . . . is the development of a vaccine for foot-and-mouth disease from one of the four proteins that make up the protein coat of the foot-and-mouth virus. This is the first time such a vaccine has been produced from the noninfectious fraction of a virus. As a result of this research, work is in progress to sequence the amino acids that are involved in producing immunity. Future vaccines may be made from noninfectious fractions of a single virus protein and may even be synthesized. These results are applicable to the control of human virus infections as well as animal virus infections.
- *Laser Ranging Observations of the Moon* (Air Force). One part of this analysis, conducted by Lt. Robert W. King, has enabled

[2]Most of the material in this section is either quoted or summarized from the agency submissions in Part I.

more accurate determination of certain geodetic parameters that affect Air Force weapons systems. Another part has led to an experimental result, which, according to the Air Force, is "of fundamental scientific significance: namely, that the mass responsible for an object's inertia is equivalent to the mass responsible for its gravity field. This is the equivalence principle, the cornerstone of Einstein's theory of relativity. According to several recent theories of gravitation, however, the gravitational and inertial masses of an object are not exactly the same if the gravitational self-energy of the object varies with its position in a gravity field. Such a failure of the equivalence principle could not be detected in a laboratory experiment, but it would cause an anomalous monthly variation of one meter or more in the moon's motion about the earth. Lt. King's five-year analysis of lunar ranging data has shown that there is no such variation to within the accuracy of the range observations, about 15 cm."

- *Endorphin Research* (NIDA): . . . The discovery of endogenous morphine-like substances (endorphins) in the brain of man and other vertebrates is a major milestone in the efforts to understand the mechanisms of action of narcotic drugs. Endorphins may be involved in the addictive process itself, that is, in the development of tolerance and dependence in opiate (heroin) addicts. 'Endorphine deficiency' might be identified as a genetic or acquired trait that predisposes some subjects to become victims of opiate dependence. The clarification of this notion by intensive research efforts should be of significance in developing new treatment modalities or in designing better and more effective prevention strategies for opiate addiction.

- *Enzyme Transporters and Genetic Disorders* (NSF). Building on knowledge only recently acquired in basic research on cell membranes, scientists at New York University (NYU) have taken an important step toward treating some genetic disorders. Manmade liposomes—artificial membranes—appear to be able to carry enzymes to cells unable to manufacture their own. The approach got a big boost recently when Gerald Weissmann and his colleagues successfully used it to "cure" Tay Sachs disease in a test tube.

  There are at least 30 human genetic disorders—Tay Sachs is one—in which certain cells don't produce a specific enzyme needed for normal functioning. But as Weissmann explains, merely injecting a missing enzyme to treat the defect doesn't work; the body's immune system rapidly engages and destroys the foreign protein. What is needed is some kind of biological "Trojan horse" that can evade immune surveillance and deliver the enzyme. Liposomes offer such a solution. For one thing, they can trap and ferry enzymes. Weissmann and his colleagues have discovered how to camouflage the liposome so that it not only escapes immune assault but also manages to deposit its valuable cargo into enzyme-deficient cells. Thus the NYU scientists succeeded in causing cells taken from a patient with Tay Sachs disease to ingest liposomes loaded with the enzyme that is missing in the invariably fatal disorder. Following that favorable result, intense efforts are now underway to find ways to apply the technique clinically.

  Weissmann also has high hopes for the technique in the treatment of local tissue inflammation brought on by the release of tissue-injuring enzymes. The idea would be to treat diseases such as arthritis by introducing into the afflicted area liposomes laden with agents that inhibit the action of the inflammatory enzymes.

- *Deep Sea Drilling Program* (NSF): . . . Since 1968, NSF has supported the Deep Sea Drilling Program (DSDP) (Scripps Institution of Oceanography). The Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES) provide scientific advice to the project. This has been the most successful large-scale study of the earth ever attempted, and it has provided the basic results on which proof of continental drift and sea-floor spreading is based. Over 50 separate cruises have now been completed. To date, 36 volumes detailing concise results have been published. A wide range of current literature in geology, geophysics, geochemistry, and their marine counterparts is based on the results of the project.

- *Slow Viruses and Neurologic Diseases* (NIH): . . . An important recent accomplishment in biomedical research is recognition of the role played by what are known as 'slow' or 'latent' viruses in disorders of the central nervous system. These pathogens are viral-type agents that require a long course of action—months or years—before the consequences of the infection become manifest in illness or disturbed function. The first recognition of their delayed action in human disease came from a study of kuru, a severe motor disability resulting from cerebellar

degeneration that occurred only among isolated tribes of natives in the highlands of New Guinea.

. . . For his discovery that kuru and another degenerative and dementing disorder of the human nervous system can be caused by transmissible virus-like agents, Dr. D. Carleton Gajdusek of the National Institute of Neurological and Communicative Disorders and Stroke (NINCDS) was awarded the 1976 Nobel Prize in medicine. . . . Dr. Gajdusek is now coordinating a worldwide collaborative effort to determine the role of kuru-like agents in human disease. What has been discovered thus far may be only the tip of the iceberg; similar slow or latent viruses may be implicated in many of the more common chronic and degenerative diseases of the nervous system.

- *High-Energy Physics* (ERDA). Among its many recent achievements, ERDA-supported research has revealed the presence of "a fourth 'charmed' quark and a possible new lepton as among the short list of the most basic constituents of matter and energy (which earlier was limited to three quarks, four leptons, and their antiparticles). The experiments suggest that the quark binding energy in hadronic matter may exceed the GeV range and may be the manifestation of a new basic force. It appears increasingly likely that all of the basic types of forces may be unified in a single framework analogous to the equations of Maxwell (which unified electrical and magnetic forces) and Einstein (which unified mass and energy)."
- *Archeological Theory* (Smithsonian): . . . (Smithsonian) scientists have recently discovered two archeological sites in northeastern Colorado which indicate that man has been in the New World nearly 20,000 years earlier than the previously accepted dates of 11,500 BP. Working near Wray, Colorado, this expedition unearthed the most complete Pleistocene record yet discovered of man's cultural history in the Americas. The localities, known as the Dutton and Selby sites, contain evidence that ice age hunters killed and butchered extinct megafauna such as a mammoth, ground sloth, peccary, giant bison, camel, horse, as well as deer and antelope. These ancient hunters, with known antecedents in Siberia using only bone tools, appear to be considerably more sophisticated than previously supposed. These finds will call for an entire reevaluation of archeological theory for the New World.
- *Reverse Osmosis* (OWRT, Interior):. . . (B)asic studies sponsored by the Office of Saline Water led directly to development and commercialization of the reverse osmosis process. This process will make up a major portion of the Bureau of Reclamation's Yuma Desalting Project which will provide 100 million gallons of fresh water (per day) for Mexico." The basic research program which led to this application has continued. Basic polymer studies performed by several organizations for the Office of Saline Water led to a new composite membrane which investigators in the Fluid System Division, UOP, Inc., are working to perfect for desalination of sea and brackish waters.

Historical Perspective

Although the sciences were considered essential to the intellectual and pragmatic needs of the Nation since its founding, the evolution of Federal support for research was slow. Lacking specific Constitutional authority to support research, the Congress was reluctant in the early years of the Republic to appropriate funds for this activity. The Army was the first agency to undertake a major basic research task for the Government—the Lewis and Clark Expedition of 1804-06. It was not until 1807 that the first continuing scientific activity—the Coast Survey—was authorized. Despite the fact that the Constitution did provide specific authority for granting inventors exclusive rights, the permanent office of the Commissioner of Patents was not established by the Congress until 1836.

The number and stature of scientific bureaus began to multiply in the latter part of the 19th century, e.g., the Geological Survey and the Department of Agriculture bureaus related to research. At the turn of the century Government institutions, e.g., the Bureau of Standards and the Bureau of Mines, began supporting research in industry. Research budgets were small but much was accomplished. Laboratory equipment was not highly sophisticated or very expensive and salaries were low.

Yet at the outset of World War I, the United States lacked an adequate base of research in both the Army and the Navy. Although the Navy had a modern fleet, both services needed scientific help to combat the weapons they encountered. The National Research Council was created as a working arm of the National Academy of Sciences and proved very effective. Immediately after the war research was cut back sharply in an

economy move. One legacy of the war, however, was the Naval Research Laboratory, which, though small, received continuous support for long-range research.

Social science became of greater interest to the Government during the Depression; medical research also prospered in the Public Health Service. Efforts to relieve financial distress and unemployment of professionals in the natural sciences ran into many complications, however.

Fortunately, the Nation had a wealth of very competent scientists, and they succeeded in calling attention to our poor state of preparedness for war. With the outbreak of World War II, the Office of Scientific Research and Development was formed. Its scientific contributions were critical to winning the war. The development of the atomic bomb, radar, sonar, influence fuzes, superior aircraft, and electronic countermeasures convinced the Government of the need for ongoing research. The Government continued support of research after the war with the Office of Naval Research, the Atomic Energy Commission, and the Public Health Service, followed shortly by the National Science Foundation. A great deal of this research was performed in universities. Although the universities were concerned about where this support would lead them, they have been an important element of Government-supported basic research ever since.

Important in-house laboratories and Federally Funded Research and Development Centers also came into being following World War II, but the postwar enthusiasm for research soon began to wane. Interest in research was renewed, however, when the Soviet Union put the first satellite into orbit. The USSR succeeded in sending a man into space and bringing him back safely. The Government responded by establishing the National Aeronautics and Space Administration and a large man-in-space program. At the same time it increased its commitment to basic research in other fields.

The present program of basic research, although somewhat less in constant dollars than it was at its peak, is still large and varied, and that which is supported by the mission agencies is important not only to them but also to the Nation.

Limitations of the Report

Accurate description of the extent and accomplishments of basic research within the mission agencies is limited by several factors, including:

- The difficulty of making a sharp distinction between basic and applied research;
- The absence of submissions from agency laboratories;
- The absence of submissions from some agencies; and
- The exclusion of program and agency reports and reviews that were underway or completed during preparation of this report.

Several agencies expressed difficulty in distinguishing between basic and applied research, and the definitions used by some agencies differ appreciably from those employed by NSF. The following quotations from agency submissions are illustrative:

- **Agriculture:** . . . Within the (Agriculture) system, basic research is generally inseparable from other research in both planning and conduct.
- **U. S. Geological Survey:** . . . The Geological Survey's operating definition of basic research is research that advances man's understanding of earth science and related natural science processes and phenomena. . . . Most of the activities of the Survey are founded on the information gained from the basic research program. In short, basic research is the cornerstone of the Geological Survey's mission.
- **Energy Research and Development Administration:** . . . Even within ERDA, different definitions of basic research are used in different contexts. The concept poses difficulties whenever the utility of expected results is a criterion for choosing research tasks.
- **Environmental Protection Agency:** . . . There is no official differentiation between basic and applied research in EPA. . . (W)hich research falls into which category is open to debate.
- **National Science Foundation:** . . . (Basic research) is systematic, intensive study directed primarily toward greater knowledge or understanding of the subject studied, rather than a practical use of this knowledge or understanding.
- **Smithsonian Institution:** . . . For basic research, the end product is commonly thought of as investigation for the advancement of scientific knowledge in general. The goal of applied research is usually described as the discovery of new scientific knowledge with a specific objective in mind.

The following quotation from the **National Institutes of Health** perhaps sums up the dilemma best:

Although these conceptual distinctions can be made, it must be noted that basic and applied research form a continuum, and a specific research project may be basic from one point of view and applied from another. This fact makes

it difficult and in some cases meaningless to classify individual projects as either basic or applied; it is usually more meaningful to speak of research as having basic and applied aspects.

Most agencies indicated that the same research project could be considered basic by the performer of the research and applied by the provider of funds. This difference in viewpoint can lead to a serious anomaly in statistical data on the support of basic research. In one NSF publication, for example, Federal Government support of basic research in 1977 is reported as $3,530 million.[3] Another NSF publication reports total Federal obligations for basic research in 1977 of $2,755 million.[4] The former figure represents the viewpoint of the performers of basic research; the latter figure, that of the Government agencies supplying the funds. The difference amounts to almost $800 million for a single year.

The statistical data also must be used carefully because some agencies that prefer not to distinguish between basic and applied research report basic research obligations on a formula basis as a certain percentage of total research funds. Other agencies make a distinction between basic and applied research but find themselves forced to be somewhat arbitrary in fixing the dividing line. Another source of discrepancy occurs when functions are transferred or missions redefined within an agency. As a result, the reported figures fluctuate but do not reflect any real changes in program.

Nevertheless, data reported by other agencies for analysis by NSF's Division of Science Resources Studies usually are internally consistent and exceedingly useful for analyzing trends. Use is made whenever possible in this report of the data reported in the series of publications entitled *Federal Funds for Research, Development, and Other Scientific Activities.* The analysis focuses on data through fiscal year 1977 but, for comparison purposes, estimates are included for FY 1978, along with the President's budget request for FY 1979 (Appendix K).

Time did not permit submissions from agency laboratories or field stations or interrogation of laboratory personnel. Thus, it should be noted that the answers to some questions and perspectives on some issues may not reflect the viewpoint of the performer of basic research.

The fact that agency submissions were prepared during a period of presidential transition caused some difficulties and delays. In addition, no information was obtained from some agencies that may conduct or support basic research. These include the **Food and Drug Administration, National Institute for Occupational Safety and Health, National Endowment for the Humanities, Center for Disease Control,** and **National Institute of Juvenile Justice and Delinquency Prevention.**

Finally, some program and agency studies that may well influence changes in agency programs and organization are not reflected in this report. Some of these were reviews by external groups, primarily committees of the National Academy of Sciences, and were underway or completed during preparation of this report; they have been used in congressional hearings on agency programs and organization. Among the reports by external groups are:

- "Understanding Crime: An Evaluation of the National Institute of Law Enforcement and Criminal Justice" (Committee on Research on Law Enforcement and Criminal Justice, National Academy of Sciences).
- "World Food and Nutrition Study: The Potential Contributions of Research" (Steering Committee, NRC Study on World Food and Nutrition, National Academy of Sciences).
- "Fundamental Research and the Process of Education" (Committee on Fundamental Research Relevant to Education, National Academy of Sciences).
- "Analytical Studies for the U.S. Environmental Protection Agency" (National Academy of Sciences, various commissions and committees, 11 reports).

Organization of the Report

Part I of the report consists of the presentations made by each agency. They show considerable variation in both program size and sophistication of management and marked differences in how basic research is defined. Some agencies indicate they have felt negligent in not doing more basic research and are in the process of increasing the basic research component of their programs. Some agencies acknowledge that basic research can enhance the performance of their missions even though they report no basic research at present.

Part II of the report was prepared by the Board and its staff using material provided by the agencies. The discussion includes descriptions of agency programs, broken down by performers of the research and by fields of science. A chapter on

[3] *National Patterns of R&D Resources, Funds, and Manpower in the United States, 1953-1977,* NSF 77-310, p. 4.

[4] *Federal Funds for Research, Development, and Other Scientific Activities,* Vol. XXVI, NSF 77-317, p. 49.

management describes facets of agencies' organizational structures and operating mechanisms. Separate chapters focus on effects of legislation, barriers, and interagency coordination. A final chapter on priorities and gap areas summarizes these items as they were listed by the various agencies.

Part III is a historical survey of scientific research activity by the United States Government since the founding of the Republic.

The **Appendices** contain documentation of the methodology used and tables of general applicability. Also included are a listing of abbreviations and acronyms and an index of the entire report.

PART I

AGENCY SUBMISSIONS

The material in this section consists of submissions by 16 major agencies and their subunits to the National Science Board for inclusion in the Board's tenth annual report. Except for minor editing, the text appears as prepared by each agency or subunit. The purpose of this section is to provide each agency an opportunity to portray the significant aspects of its basic research activities and contributions of these activities to agency objectives, to science, and to the national welfare. The agencies also were asked to include specific information such as policies concerning support of basic research, lists of the most significant projects carried out in the last 10 years, and research priorities for the future. (For further detail on the guidance given to the agencies, see the Appendices to this Report.) On the other hand, they also were encouraged to include any material they felt relevant to the topic. The names that appear under each organizational title are, as indicated, those officials either responsible for preparing or submitting the material while this Report was under preparation in 1977. It has not been possible to include all organizational and policy changes that have occurred since submission of material by the agencies.

DEPARTMENT OF AGRICULTURE

A. R. Bird, Economic Research Service (ERS); L.L. Jansen, Agricultural Research Service (ARS); D.B. Johnson, Forest Service (FS); and J.C. Williamson, Cooperative State Research Service (CSRS) constituted a special work group that developed this report. D.J. Ward, Office of the Secretary, had general responsibility for arranging for the response to the National Science Board request.

The work group members were assisted by special committees or groups drawn from national staffs within their respective agencies. Inputs representing cooperating State agricultural research organizations were provided by the technical staff of the Cooperative State Research Service. G.C. Taylor participated in the work group at times for ERS, T.S. Ronningen for CSRS, and R.G. Krebill for FS. J.R. Myers of the Current Research Information System (CRIS) served as consultant to the work group.

Mission of the Department of Agriculture

Broadly stated, the research mission for the publicly supported agricultural research system is: To increase scientific knowledge and to produce technical information and technical products that will contribute to the development and maintenance in the United States of permanent and effective agricultural and forestry industries, in their broadest aspects; the development and improvement of the rural home and rural life; the contribution of agriculture and forestry to the welfare of the American people and their environment; and the promotion of human welfare and world peace. Agricultural and forestry research will give due regard to the varying conditions in all the regions of the Nation and to the needs of the people in all the States and Territories.

The United States Department of Agriculture (USDA) was established by the Organic Act of 1862. Through authorizing legislation in the Hatch Act of 1887, the Adams Act of 1906, the Purnell Act of 1925, the McSweeney-McNary Act of 1928, the Bankhead- Jones Act of 1935, the Agricultural Marketing Act of 1946, the Agricultural Trade and Development and Assistance Act of 1954, Public Law 89-106 (Special Grants Act) of 1965, the Rural Development Act of 1972, and the McIntire-Stennis Act of 1962, the USDA has established research cooperation with and funding support of the State Agricultural Experiment Stations (SAES), State forestry schools, the colleges of 1890, and the Tuskegee Institute.

Six agencies in the Department conduct or fund research in the context of the above research mission, although their research function is more formally documented as supportive activities of one or more of the Department's missions. All activities of the Department are now covered under 11 broad missions that characterize the Department's role in solving broad, national problems. Mission-oriented research is conducted by the Agricultural Research Service (ARS), the Economic Research Service (ERS), Farmer Cooperative Service (FCS), Forest Service (FS), Statistical Reporting Service (SRS), and cooperating State research organizations funded through the Cooperative State Research Service (CSRS). Basic research is conducted as an integral part of the Department's research programs.

The research arms of the State agencies and institutions, together with the USDA research agencies, are the publicly supported agricultural research system. The structure and relationship among the major performing organizations are described in detail later on.

The distribution of research among the performing organizations (Table 1) clearly reflects the major roles played by ARS and SAES in agricultural research and by FS in forestry research. The distribution of effort by science categories (Table 2) shows the heavy concentration of research among biological sciences, with those that are plant-oriented accounting for a major part. USDA research ranges from one-fourth to one-third of total effort in biological research. Except for some social sciences, levels of USDA research exceed or are at least equal to State efforts in

most other science categories. All efforts are complementary when examined in detail.

Table 1. Distribution of full-time equivalent research scientists (scientist-years) in the U. S. Department of Agriculture and State agricultural and forestry research organizations, FY 1975.

Research Agency or Organization	*Full-Time Equivalent Research Scientists*[1] *Number*	*% of total*
USDA:		
Agricultural Research Service	2,910	27
Economic Research Service	425	4
Farmers Cooperative Service	23	<1
Forest Service	941	9
Statistical Reporting Service	15	<1
STATE:[2]		
Agricultural Experiment Stations	6,133	57
Forestry Research Organizations	143	1
1890 Land Grant Universities and Tuskegee Institute	143	1
Total	10,732	100

[1]Individual values may not agree with totals because of rounding.

[2]Supported in part by the Cooperative State Research Service (CSRS) of USDA.

Source: USDA

Definition of Basic Research

For purposes of documenting agricultural research in the computerized current research information system (CRIS), basic research is distinguished as "research with the primary goal of gaining knowledge or understanding of a subject." Research that has as its primary goal the application of knowledge to meet a recognized need or to produce useful products is excluded from "basic."

Within the agricultural system, basic research is generally inseparable from other research in both planning and conduct. This system is highly decentralized. Much research of individual scientists is predominantly problem-oriented and usually developed for a timeframe of five years or less. Basic aspects, however, are often incorporated to answer the "how's" and "why's" of observed phenomena or to provide additional fundamental information needed for progress on a more applied problem. In many cases, such research areas as photosynthesis, nitrogen fixation, and insect behavior are pursued because of their explicit value and broad potential for application. Occasionally, pursuit of an applied problem generates a new area of explicit basic research. An example of this is R.W. Holley's experiments to understand how nutrient elements are moved from the soil into foods and feeds, a practical problem, which eventually led to his elucidation of the structure of ribonucleic acid (RNA) molecules, for which he was awarded a Nobel prize.

Basic research in the agricultural research system varies considerably among the broad science categories and within the biological sciences among the types of subjects being researched. Table 3 shows the allocation of funds for basic research by science category and the relative proportion of the total funds for the category that the basic funds represent. In actual magnitude, biological sciences receive more basic research funds than any other science category, and plant-oriented sciences account for at least 50 percent of these funds. However, human-oriented and other biological sciences have a much higher proportion of total funding allocated to basic studies.

Overall, during the past 10 years, basic research in the total agricultural research system has received increased support in terms of both actual and constant dollars. However, the proportion of basic to other research has remained more or less constant. The changes that have occurred in programs of individual performing organizations are summarized in Table 4.

Role of Basic Research

In developing an overall research strategy for the agricultural and forestry system, scientists and managers give consideration to all areas of research in the continuum from the most basic to the most applied. The strategy is to allocate available resources over time among problem areas in this basic-applied research continuum in such a way as to make a maximum contribution to their missions. In the process of determining appropriate levels of support at any point in time for different areas of research, basic research is viewed by research planner-administrators as having the following functional roles in the continuum of research activities:

1. Creating new knowledge that will be useful in advancing future agricultural research at the basic or applied levels, or in advancing

Table 2. Distribution of scientist years (SY's) by major science categories in USDA and State agencies, FY 1975.[1]

Science Categories	USDA SY's	USDA Percent of Agency Total	STATES[2] SY's	STATES[2] Percent of Agency Total	NATIONAL TOTAL SY's	NATIONAL TOTAL Percent
Biological Sciences	2,391	55	4,583	71	6,974	65
Animal-oriented	494	11	1,421	22	1,915	18
Plant-oriented	1,699	39	2,800	44	4,499	42
Human-oriented	99	2	161	3	260	2
Other	99	2	201	3	300	3
Chemistry/Physics	712	17	483	8	1,195	11
Engineering	477	11	342	5	819	8
Environmental Sciences	127	3	100	2	227	2
Mathematics and Statistics	46	1	46	1	92	1
Economics	522	12	535	8	1,057	10
Other Social Sciences	38	1	214[3]	3	252	2
Unclassified	–	–	116	2	116	1
Total	4,313	100	6,419	100	10,732	100

[1]Individual values may not add to total due to rounding.

[2]Includes State Agricultural Experiment Stations, State Forestry Schools, Colleges of 1890, and the Tuskegee Institute.

[3]Includes 133 SY's sociology, 34 SY's education, and 20 SY's psychology.

Source: USDA

technology in a general area of agricultural applications. These may be characterized as pure basic research and as mission-oriented basic research, respectively.

2. Creating new knowledge that will be useful in solving an identified problem in agriculture. Such basic research may be viewed as mission-contributing or mission-supportive, depending upon whether the identified problem is more or less specific.
3. Providing a sufficient base of scientific expertise to link with the scientific community at large so that applicable scientific advances, wherever they may occur, may be interpreted and used to advance the agricultural research mission.
4. Contributing to the range and diversity of scientific expertise needed in the process of research program planning, evaluation, and development.

Examples of Basic Research

The examples of recent and on-going basic research cited in this section reflect the mission-oriented character of such research in the USDA and the cooperating State agricultural research organizations. They range from the pure basic through mission-oriented and mission-supportive basic research to mission-contributing basic research and touch on only some of the many fields of science in which basic research has been performed.

Development of Vaccines for Control of Animal Diseases

Research to develop vaccines for the control of animal diseases continues to be given emphasis. Significant break-throughs include the development of a vaccine for Marek's disease, a cancer-causing disease in chickens. This has been an outstanding achievement in the field of virus-in-cancer and has reduced large economic losses due to this disease by a dramatic 80 percent. Another recent significant scientific achievement is the development of a vaccine for foot-and-mouth disease from one of the four proteins that make up the protein coat of the foot-and-mouth virus. This is the first time such a vaccine has been produced from the noninfectious fraction of a virus. As a result of this research, work is in progress to sequence the amino acids that are involved in producing immunity. Future vaccines may be made from noninfectious fractions of a single virus protein and may even be synthesized. These results

Table 3. Funds allocated for basic research by performing agricultural research organizations and by science categories, FY 1975.[1]

Science Category	ARS		FS		ERS		SRS[a3], FCS[b3]		States[2]		National Total	
	Funds	PCT	Funds	PCT	Funds	PCT	Funds	PCT	Funds	PCT	Funds	PCT
Biological Sciences	$66.7	46	$14.4	32					$132.3	38	$212.3	39
Animal-oriented	25.1	51	1.2	57					51.8	38	78.1	42
Plant-oriented	32.1	41	13.0	30					67.2	35	112.3	36
Human-oriented	4.8	65	.1	25					4.4	41	9.2	50
Other	3.7	60	.1	83					8.9	57	12.7	58
Chemistry/Physics	15.0	36	1.8	41					11.8	37	28.6	37
Engineering	5.5	22	1.5	17					5.3	23	12.3	22
Environmental Sciences	1.0	34	1.7	20					2.6	33	2.0	33
Mathematics/Statistics	.2	22	.6	50			[a].1	23	1.1	33	2.0	33
Economics	.3	15	.4	9	$3.1	15	[b].1	7	5.4	19	9.3	16
Other	.1	30	.1	10	.1	10	[b].1	71	3.6	12	4.1	13
Agency Totals	$87.8	41	$20.4	28	$3.2	15	[a].1 [b].2	23 15	$162.1	34	$273.9	35

[1]Funds in millions of dollars; PCT = percent of total funds for each science category expended for basic research. Figures may not add to totals because of rounding.

Source: USDA

[2]"States" includes State Agricultural Experiment Stations, State Forestry Organizations, Colleges of 1890, and the Tuskegee Institute.

[3]Superscript "a" equals SRS only; superscript "b" equals FCS only.

are applicable to the control of human virus infections as well as animal virus infections.

Bachrach, H. L. and J. Polatnick. 1967. Amino acid composition of three immunological types of foot-and-mouth disease virus (31765). Proc. Society of Experimental Biol. and Medicine, 124:465-469.

Bachrach, H. L., D. M. Moore, P. D. McKercher and J. Polatnick. 1975. Immune and antibody responses to an isolated capsid protein of foot-and-mouth disease viruses. Jour. of Immunology, 115: 1636-1641.

Matheka, H.D. and H. L. Bachrach. 1975. N-terminal amino acid sequences in the major capsid proteins of foot-and-mouth disease virus types A, O, and C. Jour. of Virol., 16:1248-1253.

Okazaki, W., H. G. Purchase and B. R. Burmester. 1970. Protection against Marek's disease by vaccination with a herpesvirus of turkeys. Avian Dis., 14:413-429.

Purchase, H. G., R. L. Witter and W. Ikazaki. 1971. Vaccination against Marek's disease. Perspectives in Virology, 7:91-110. Academic Press, Inc. New York.

Improvement of Reproductive Performance in Animals

A successful procedure has been developed for deep-freezing of swine semen allowing artificial insemination to aid the swine industry to make maximum use of superior sires. The process of freezing has been improved whereby the required number of sperm per insemination and the storage volume per insemination has been reduced. Also, a semen extender and a freezing method for poul-

Table 4. Total actual and relative funding of basic agricultural research by performing organization, FY 1968, 1972, and 1975.

	FY	Basic funds ($ millions)	% Basic	1972 constant ($ millions)[1]
ARS	68	$ 60.8	43	$ 78.6
	72	76.9	41	76.9
	75	87.8	41	68.4
ERS	68	3.8	29	4.9
	72	4.6	27	4.6
	75	3.2	15	2.5
FS	68	12.7	33	16.4
	72	16.8	30	16.8
	75	20.4	28	15.9
STATES	68	72.2	29	93.3
	72	118.3	33	118.3
	75	162.1	34	126.3
NATIONAL TOTAL[2]	68	150.2	34	194.1
	72	216.9	35	216.9
	75	273.9	35	213.5

[1]Adjusted data (1972 = 100) for Government purchases of goods and services, in Table B-3, "Implicit Price Deflators for Gross National Product 1929-76." Economic Report of the President transmitted to the Congress January 1977.

[2]National Total includes a small amount of basic research performed by Farmer Cooperative Service and Statistical Reporting Service, USDA. Total research performed by these Agencies is very small.

Source: USDA.

try semen is now available commercially.

Significant advancement has been recently made in the area of pregnancy testing in sheep. Research led to development of techniques to determine fetal numbers in pregnant ewes, a very important development for the sheep industry because twinbearing ewes can now be identified for selection purposes.

Hutlet, C. V. 1972. A rectal-abdominal palpatation technique for diagnosing pregnancy in the ewe. Jour. of Animal Sci., 35:814-819.

Hutlet, C. V. 1973. Determining fetal numbers in pregnant ewes. Jour. Animal Sci., 36:325-330.

Hutlet, C. V. and W. L. Shupe. 1973. Predicting multiple births in sheep by rectal-abdominal palpatation. Proc. Western Section American Soc. of An Sci., 24:237.

Mengeling, W. L., R. C. Cutlip, R. A. Wilson, J. B. Parks and R. L. Marshall. 1975. Fetal mummification associated with porcine parvovirus infection. Jour. Amer. Vet. Med. Assoc., 166:993-995.

Mengeling, W. L. and R. C. Cutlip. 1976. Reproductive diseases experimentally induced by exposing pregnant gilts to porcine parvovirus. Amer. Jour. Vet. Research, 37: 1393-1400.

Pursel, V. G. and L. A. Johnson. 1971. Procedure for the preservation of boar spermatozoa by freezing. ARS: 44-227.

Pursel, V. G. and L. A. Johnson. 1971. Fertilizing capacity of frozen boar spermatozoa. Jour. Animal Sci., 33:1162 (Abstract).

Discovery of Important Disease-Causing Enteric Viruses in Cattle and Swine

Utilizing germ-free animals, new viral agents were identified that cause major losses from enteric disease in cattle and swine. The causative agents have been classified as belonging to the parvo, rota, reo, and corona classes of viruses. Association of the viral agents with the enteric diseases and their classification became feasible through the simultaneous development by the same investigators of new laboratory procedures that utilize fluorescent antibody techniques with the aid of electron and immune-electronmicroscopy.

Enteric diseases cause a high proportion of all mortality and morbidity in young calves and pigs. Annual losses in swine are estimated to cost the industry $150,000,000, and calf losses equal nearly 10 percent of all calves born. Basic information on these enteric viruses will permit the development of vaccines and preventative practices which will be of great economic importance to the livestock industry. The interrelations between animal and human disease are shown by studies that indicate that an isolated rotavirus from human infants was capable of causing enteritis in germ-free pigs. The reovirus-like agent has also been shown to be ubiquitous in nature causing diarrhea in infants, calves, pigs, monkeys, and mice.

Bohl, E. H. and L. J. Saif. 1975. Passive immunity in transmissable gastroenteritis of swine: Immunoglobulin characteristics of antibodies in milk after innoculating virus by different routes. Infection and Immunity 11:23.

Mebus, C. A., R. G. White, E. L. Stair, M. B. Rhodes and M. J. Twiehaus. 1972. Neonatal calf diarrhea: Results of a field trial using a reo-like virus vaccine. Vet. Med. Small An. Clinic 67:173.

Mengeling, W. L., Porcine parvovirus; Properties and prevalence of the strain isolated in the U.S. 1972. Amer. Vet. Res. 33:2239-2248.

Saif, L. J., E. H. Bohl, E. M. Kohler and J. H. Hughes. 1977. Immuneelectronmicroscopy of transmissable gastroenteritis virus and rotavirus of swine. Am. J. Vet. Res. 38:13.

Sharpee, R. L., C. A. Mebus and E. P. Bass. 1976. Characterization of a calf diarrheal coronavirus. Am. J. Vet. Res. 37:1031.

Torres-Medina, A., R. G. Wyatt, C. A. Mebus, N. R. Underdahl and A. Z. Kapikian. 1976. Diarrhea caused in gnotobiotic piglets by the reovirus-like agent of human infantile gastroenteritis. J. of Infect. Dis. 133:22.

Determination of the Requirements and Interrelationships of Amino Acids for Swine and Poultry

Requirements for the indispensable amino acids for growth, gestation, and lactation in swine, and for growth and egg production in poultry have been determined. Significant interrelationships between amino acids have been shown to influence quantitative needs. To aid in the application of this knowledge the relative values of the different commercially available isomers have been established.

The protein requirement for all functions in domestic animals is, in reality, the need for the proper quantity and ratio of amino acids. Worldwide protein is both the most limiting and expensive ingredient as a constituent of animal diets. As knowledge of amino acid requirements is further established, protein intake can be reduced to the level at which only required levels of amino acids are furnished. Such information is having the effect of greatly extending world protein supplies.

Baker, D. H., N. K. Allen, J. Boomgaardt, G. Graver and H. W. Norton. 1971. Quantitative aspects of D- and L- tryptophan utilization by the young pig. J. Anim. Sci. 33:42.

Featherston, W. R. and G. W. Horn. 1974. Studies on the utilization of the alpha-hydroxy acid of methionine by chicks fed crystalline amino acid diets. Poul. Sci. 53:680.

Lewis, A. J. and V. C. Speer. 1975. Threonine requirement of the lactating sow. J. Anim. Sci. 40:892.

Maruyama, K., A. E. Harper and M. L. Sunde. 1975. Effects of D-, DL- and L- glutamic acid on chicks. J. Nutr. 105:1012.

Turtle, W. L. and S. L. Balloun. 1976. Leucine, isoleucine and valine interactions in turkey poults. Poult. Sci. 55:1737.

Development and Transfer of Bacterial Resistance to Antimicrobial Compounds

A portion of the enteric bacteria of all animals may possess resistance to antimicrobial drugs commonly used therapeutically and at low levels in the feed of animals for growth promotion and disease prevention. Research on these factors (R-factors) has shown that the incidence of R-factor containing bacteria increases when antibiotics are fed and that this resistance can be transferred from one strain of bacteria to another. The potential threat to human and animal health from the acquisition of such resistance, and recognition of those practices related to the use of drugs that increase the population of resistant bacteria in our ecosystem, has developed into an important and urgent area of investigation.

A complete understanding of the nature of bacterial resistance to antimicrobial drugs is essential for the protection of animals and human health. If there is a greater risk of transfer of resistance to pathogenic bacteria from the common usage of antibiotics, the extent and nature of the risk must be established. A true appraisal of the R-factor pool in man and animals is badly needed to determine when any further change occurs as well as the significance of such change to animal and human health and to medical practice.

Gutzmann, F., H. Layton, K. Simkins and H. Jarolmen. 1975. Influence of antibiotic-supplemented feed on occurrence and persistence of salmonella typhimurium in experimentally infected swine. Am. J. Vet. Res. 37:649.

Lakhotia, R. L. and J. F. Stephens. 1973. Incidence of drug resistance and R-factor among Salmonellae isolated from poultry. Poult. Sci. 52:2266.

Nivas, S. C., M. D. York and B. S. Pomeroy. 1976. In vitro and in vivo transfer of drug resistance for Salmonella and Escherichia coli strains in turkeys. 37:433.

Walton, J. R. 1971. The public health implications of drug-resistant bacteria in farm animals. Ann. NY Acad. Sci. 182:358.

Successful Transfer of Fertilized Ova in Cattle, Sheep, and Swine

Blood hormone studies, together with surgical and laboratory procedures have established the necessary technology for successful transfer of fertilized ova in cattle and swine. Radio-immune assay techniques are being used to determine optimum timing with hormonal synchronization between donor and recipient females. Surgical procedures, techniques for superovulation, and laboratory requirements for storage and transport of ova have been developed.

The new knowledge gained of ovarian function, requirements for *in vitro* culture of ova, and the technique for transfer of fertilized ova from donor to recipient females in these species has greatly extended the potential genetic contribution of superior females. Both private and commercial applications of this technology are already apparent. Much of the basic information obtained is being applied to research on the potential for multiple births in cattle and control of litter size in swine. The greater control over ovarian function now permitted, together with a better understanding of ovarian-uterine relationships, has also provided a basis for further determining causes of prenatal death in both species.

Dziuk, P. J. 1968. Egg transfer in cattle, sheep and pigs. The Mammalian Oviduct, edited by Hafez, E. S. F., and Blandau, R. J., p. 407. University of Chicago Press.

Rowson, L. E. A., R. A. Moor and R. A. S. Lawson. 1969. Fertility following egg transfer in the cow: effect of method, medium and synchronization of oestrus. J. Reprod. Fertil. 18:517.

Seidel, G. E., Jr., L. L. Larson, C. H. Spilman, J. Hahn and R. H. Foote. 1971. Culture and transfer of calf ova. J. Dairy Sci. 54:923.

Wright, R. W., P. T. Cupps, M. Drost and G. E. Bradford. 1974. Culture of sheep and cow ova in various media. Proc. West. Section Am. Soc. An. Sci. 25:293.

Discovery of Biological Function of Alpha-Lactalbumin

Alpha-lactalbumin is a protein found in the skim milk of many species. It is one of two proteins required for the lactose synthetase enzyme, the enzyme responsible for biosynthesis of lactose in the mammary gland or in a test tube. This discovery resulted from efforts to purify the enzyme from bovine skim milk into two fractions A and B. There was no enzyme activity in either protein A or protein B tested separately, but the presence of both proteins A and B gave significant enzymatic activity. Protein B was shown to be alpha-lactalbumin, a relatively low molecular-weight substance, and a subunit in the enzyme structure. This subunit has been considered a "specifier protein," having the ability to change the catalytic activity of an existing protein, similar to other enzymes that have regulatory subunits.

Current work on lipid metabolism, rather than the above carbohydrate metabolism, is finding the "specifier factor" to be a useful concept in synthesizing fats with liver microsomes.

Brodbeck, U. and K. E. Ebner. 1966. The subcellular distribution of A and B proteins of lactose synthetase in bovine and rat mammary tissue. J. Biological Chemistry, 241, 5526-5532.

Ebner, K. E. and Brodbeck, U. 1968. Biological role of alpha-lactalbumin. A review. J. Dairy Science, 51, 317-322.

Ebner, K. E. 1970. A biological role for alpha-lactalbumin as a component of an enzyme requiring two proteins. Accounts of Chemical Research, 3:41-47.

Tsai, C. M., N. Holmberg, and K. E. Ebner. 1970. Purification, stabilization, and properties of bovine mammary UDP-galactose 4-epimerase. Arch. Biochem. Biophys., 136:233-244.

Expansion and Improvement of Crop Germplasm Resources

The USDA plant introduction system acquires 7,500 to 10,000 new items annually. Sizeable effort is involved in the characterization, documentation, and manipulation of the existing germplasm bases into forms that are useful in crop-breeding programs, the ultimate output of which are the more than 200 improved breeding lines and varieties released annually. Much basic effort is involved in characterizing physiological, biochemical, quality, and other attributes; determining the nature of resistance to pests and stresses; determining mechanisms of inheritance; and devising improved genetic techniques and evaluation procedures to facilitate the germplasm effort.

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Photosynthesis

All research on photosynthesis is necessarily mission-oriented, since this process accounts directly or indirectly for all food production. Significant basic research contributions in the past decade have increased our understanding of important enzymatic reactions, biochemical mechanisms, interactions with respiration, the significance of environmental and chemical variables, energy balances, and canopy efficiencies under field conditions. Computer models of photosynthesis and respiration are now facilitating the identification of important gaps in knowledge and the evaluation of stochastic variables.

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Nitrogen Fixation

Basic research has contributed new knowledge on the genetics of rhizobium (the best known of the nitrogen-fixing microorganisms), on toxic substances produced by this bacterium, and on environmental factors controlling nitrogen-fixing processes. Other advances have been made in our knowledge of the nitrogen cycle and plant absorption and utilization of nitrogen in its various forms. Since nitrogen makes up a major part of the fertilizers used in crop production, understanding these processes is critical to development of sound fertilizer conservation practices. Petroleum based fertilizers currently account for 35 percent of the total energy used in crop production.

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Increased knowledge of the physiological and biochemical effects of a large number of environmental stress factors and development of effective remote sensing technology contribute to development of better protection methodology and modeling for predictive purposes.

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Plant Growth Regulation

Increased potential for practical control of plant growth and development with both naturally occurring and synthetic growth-regulation substances has been achieved through discovery and evaluation of new chemical substances and determination of their mechanism of action. Application of such technology is having significant impact on production practices, harvesting, and curing of tobacco, and has created new potential uses for tobacco as a food.

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Biological Control of Insects

Advances in the past decade in the discovery, identification, and synthesis *in vitro* of sex-stimulating and food-locating chemicals opens the possibility of disrupting one or more vital processes in insects in locating specific food plants and in aggregating on susceptible plants. These advances provide an important new tool that permits man to manage insect populations onto sites or into situations where they can be destroyed or fail to fulfill a vital stage in their life history.

Studies of insect hormone systems have led to potential methods of disrupting growth and maturation of insects in nature by the application of small amounts of synthetic hormones. Hormones that disrupt the synthesis and breakdown of chitin in the insect cuticle are finding application both in agriculture and in controlling insects that attack man. The characterization of indigenous pathogens of insects has provided better understanding of the mortality factors influencing insect populations. Two classes of pathogens, bacteria and viruses, are now commercially produced for insect control in agriculture, forestry, and urban environments. The pathogens do not interfere with, but augment other biological control methods. Studies on insect genetics have resulted in the potential use of the hybrid sterility principle where the mating of a harmless species with a pest like the tobacco budworm results in sterile male offspring.

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Plant Virology

Techniques to isolate and identify viroids resulted in special gel electrophoresis and sedimentation techniques now universally utilized. Using these techniques, it was conclusively demonstrated that infectious RNA (viroids) has a low molecular weight and that viroids therefore differ basically from conventional viruses. Development and improvements in freeze-etch and related techniques have made electron microscope assays of biological specimens so rapid the medical sci-

ences are utilizing the techniques for biopsy studies while a patient is still on the operating table. Other research led to the discovery of a new class of organisms named spiroplasmas. It has been proven that spiroplasmas are the causal agents of several plant diseases including the corn stunt disease. Spiroplasmas can now be cultured and provide a means by which new vectors and unknown plant hosts can be identified. From basic RNA studies of the cucumber mosaic virus (CMV), a fifth RNA was recently discovered. When RNA 5 is present, CMV causes severe tomato necrosis. This discovery explains the cause of the disastrous loss of tomato production in France in 1972.

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Alleviation of Root Diseases by Antibiosis

Many soil saprophytes have been found to produce antibiotic substances that suppress or destroy plant pathogens, and some saprophytes actually parasitize or debilitate harmful organisms. The best possibility of alleviating plant diseases caused by soil inhabiting fungi, bacteria, and nematodes is to manage soils to increase the antibiotic potential by commensal organisms. A rich field soil regularly contains up to 2 million organisms per gram, each competing for space and nutrients and producing metabolic products that influence the welfare of neighboring organisms. The pattern for using this knowledge is being well-established by research now in progress. Additional research is needed on the biochemistry of antagonisms and on isolating, identifying, and learning how to use the inhibitory substances.

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Plant Breeding for Improved Productivity and Resistance to Pests

Research on photorespiration has shown that plants differ drastically in their efficiency in converting carbon dioxide into carbohydrates and other storage products. Plants that undergo photosynthesis through 4-carbon chains vs. 3-carbon chains have been found twice as effective in utilizing carbon dioxide. Moreover, photorespiration inhibitors or somatic hybridization with plants of low photorespiration can enhance water utilization. In addition, recent research has indicated the potential for improved nutritional quality to animals. A single mutant gene in forage sorghum has been discovered to increase the rate of digestion of forage sorghum by ruminant animals. Discovery of opaque-2 and flour-2 genes in maize has increased the amino acid balance for nonruminant animals. Gel electrophoresis methodology has permitted fingerprinting and classification of proteins for rapid screening by plant breeders.

Much early research on breeding for pest resistance gave ephemeral results due to the pest's ability to produce new races. Recent research resorting to multigenic or broad forms of resistance geometrically reduces the chances of the pest to readjust according to the number of genes involved. Using this approach, resistance to late blight fungus in potatoes and black stem rust in wheat has been stabilized. It has also been discovered that certain cultivars produce fungicidal, bacteriostatic, or insecticidal substances when invaded by plant pests. Absence of precursors or inadequate enzyme systems for generation of these substances leaves the plant susceptible and vulnerable to attack.

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Mathematical Modeling of Plant Growth and Pest Development

Mathematical modeling techniques are simulating plant growth as affected by known input factors such as soil and environment temperatures, radiation, soil moisture, relative humidity of the air, nutrient availability, cultural practices, photosynthetic activity, etc. Various stages of plant development may be predicted with anticipated events. Pest population development can also be

predicted by similar use of modeling techniques and the impact upon plant development predicted. With anticipated events, manageable inputs may be altered to improve production efficiency.

The mathematical modeling techniques are providing a new systems management capability for more efficient production of crops. Optimum applications of fertilizer, water, and pesticides are being determined with more efficient utilization of energy and nutrients and maximized productivity.

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McKinion, J. M., D. N. Baker, J. D. Hesketh, and J. W. Jones. 1975. SIMCOTT II: A simulation of cotton growth and yield. Computer simulation of a cotton production system, users manual. ARS-S-52.

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Storage Life of Food Crops

Extending the storage life of food crops with retention of quality and nutritive characteristics requires understanding of both postharvest physiology and mechanisms by which biological deterioration occur. Refrigeration has been the classical procedure for extending storage life; but other techniques such as manipulating and controlling the storage atmosphere, and hot-water and fungicide treatments are also proving effective. A new departure, still in the basic research stage, is the use of bioregulators.

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Fungal Genetics of Forest Tree Pathogens

The objective of forest disease research is to modify host or pathogen as necessary to make them incompatible. Work with tree rusts has involved some of the major efforts to control diseases by modifying the genetic constituency of host or pathogen. Research on white pine blister rust, an introduced disease, has yielded information from which scientists have been able to structure a program for controlling infections. Critical to the success of this program was a fundamental knowledge of fungus variation and variability of host resistance to infection. Research efforts have also yielded information that will permit limiting the effects of fusiform rust, the most serious disease of southern pines. Recent research on pathogenic variability, when coupled with knowledge of host resistance, dictates the kind of program most appropriate for controllong this disease.

Bingham, R. T., R. J. Hoff, and G. I. McDonald. 1971. Disease resistance in trees. Ann. Rev. Phytopath. 9:433-452.

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Wood Growth and Differentiation

To understand the basic properties of wood formation there must be an in-depth understanding of the physiological processes that control the growth and differentiation of wood elements in forest trees. Research on hormonal regulation of wood has contributed to the clarification of earlywood-latewood transition, reaction wood formation, branching angle, stem form, and taper. In the course of these investigations it was clearly demonstrated that the anatomical development was a limiting factor in both photosynthesis and the translocation of assimilates; thus, photosynthetic rates alone did not control growth rate or wood formation.

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Nutrient Cycling in Forest Ecosystems

Insects and fungi serve as vital links that contribute to diversity and long-term ecological development of forest communities. These agents are energy-efficient consumers contributing to the breakdown of organic matter, demise of aged and inefficient plants, hastening of forest succession,

and circulation of vital mineral nutrients needed for plant growth. Insects are an energy and nutrient-rich food source for the plethora of animals that feed on them. Research on energy flow or nutrient cycling can often supply tools to determine when pest action has a net benefit on the forest and should not be controlled.

Research on the forest tent caterpillar and other defoliating insects in the aspen-birch ecosystem of the Lake States has featured investigations into nutrient cycling and energy flow. This approach has brought new understanding of the roles of insects in forest communities. Of significance is the discovery that defoliating insects tend to optimize plant productivity of particular sites over the long term. In general, site factors that adversely affect tree hosts ultimately enhance the success of the infesting insects. This research promises to bring about a better understanding of the complex nutrient factors and interactions which are important for plant vigor and resistance to disease and which can signal the release of endemic insect populations into an epidemic phase.

Mattson, W. J. and N. D. Addy. 1975. Phytophagous insects as regulators of forest primary production. Science, 190:515-522.

Population Ecology of Forest Insects

Population ecology research usually focuses on insects assumed or proven to be forest pests. This basic research involves: (1) Developing methods describing quantitatively the populations of target insects and their associates including natural enemies; (2) evaluating the roles of natural enemies—parasites, predators, pathogens—and other associates, physical factors, and host relationships in determining population changes; and (3) developing methods to predict population changes in time and place and the effects of such changes on trees, stands, and forest ecosystems. Investigations have included the mountain pine beetle, western pine beetle, spruce budworms, and forest tent caterpillar. As a result, a broad base of knowledge is available on a wide variety of forest pests. Technology was developed, applied, and improved for sampling insect populations to gather quantitative data both in research and operational control programs. Life history and population dynamics studies have identified key life stages most susceptible to direct control actions and pointed the way toward utilizing biological control agents—parasites, predators, pathogens—as well as conventional control approaches for forest resource protection.

In recent years, efforts have intensified to develop pest management systems for the southern pine beetle, gypsy moth, and Douglas-fir tussock moth. New approaches are being used to develop models for pest populations, their effects on forest stand parameters, treatment techniques applied singly and in combinations, and interacting social and economic criteria that influence pest and forest management decisions.

Campbell, R. W. 1967. An analysis of numerical change in gypsy moth populations. Forest Sci. Monograph 15:33pp.

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McKnight, M. E. 1971. Natural mortality of the western spruce budworm, *Choristoneura occidentials*, in Colorado. USDA Forest Serv. Res. Paper RM-81. 12 p. Rocky Mt. Forest and Range Exp. Sta., Fort Collins, Colorado.

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Insect Pathology

Forest insects pests are hosts of many pathogenic mircoorganisms, and disease is known to be an important factor in the population dynamics of some of the major pests which have been studied most intensively. Broad knowledge of the occurrence and distribution of naturally occurring diseases, their effects on individuals and populations, and their modes of transmission and persistence in forest ecosystems suggests that certain pathogens of forest insects can be manipulated by man. Our experience in developing microbial insecticides has shown the essentiality of basic biological, chemical, and physical characterization of specific pathogens to establish their environmental safety. With these prerequisities fulfilled, registration of the Douglas-fir tussock moth nuclear polyhedrosis virus (NPV) has been granted (the first forest insect virus approved for operational use) by the Environmental Protection Agency (EPA), and registration of the gypsy moth NPV is expected soon. Forest Service research on NPV's and on formulations of commercially available *Bacillus thuringiensis* has provided forest managers with biological control agents for two of the most important forest insect pests of North America. With protocols for registration now established, research should move aggressively to provide more knowledge to support operational use of a variety of pathogens—viruses, bacteria, fungi, protozoa, nematodes—known to be effective against important forest insects.

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Human Requirements for Nutrients

Research is focusing on the development of recommendations for nutrient intake by humans and identification of forms of nutrients in foods that may be useful in meeting these requirements. Current research encompasses proteins, lipids, carbohydrates, minerals, and vitamins. Other areas of concentrated basic research include studies on the influence of food fat on cholesterol levels; biologically effective forms of iron, zinc, copper, and chromium; improving the basis for the recommended daily allowance (RDA) of nutrients, especially for vitamin C and B6; and determining the metabolic response to certain dietary fiber components. Another phase of this research is designed to devise quicker ways to assess the nutritional status of individuals. Examples of recent achievement include the identification of good iron availability in wheat and the isolation of an iron compound; identification of food sources of the chromium-containing "glucose tolerance factor"; magnesium requirements of adolescent boys; and probable identification of nickel as an essential human nutrient.

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Nutritional Interrelationships in Lipid Metabolism in the Human

Scientists have concentrated efforts for a number of years on research to increase knowledge of interrelationships in lipid metabolism. Principal accomplishments reported include: (1) Relationships between dietary fat and lipids in blood and other tissues—a number of dietary factors other than lipids affected serum cholesterol levels. Among the factors are feeding frequency; low protein cereal diets; diets deficient in methionine, choline, or protein; and configuration of unsaturated lipids; (2) relationships between lipids and other substances in metabolism—identified were diets high in polyunsaturated fatty acids (PUFA) or orotic acid, choline deficiency, and excessive dietary linoleic acid; (3) relationship between lipid utilization and physiological state, normal and abnormal—morphology and structural integrity of cardic tissue and PUFA, hepatic mitochondrial membranes and membrane-bound enzyme activities with diets high in PUFA; excessive vitamin D intake and cell degeneration in smooth muscle.

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Requirements of Preteenage Girls for Specific Nutrients

In research focused on nutritional requirements for preadolescent girls, two central human metabolic studies and companion animal studies were conducted. Major variables in the first study were level of protein and calcium intake. Variables in the second study were quality of protein and calcium levels. Results revealed important interrelationships among nutrients as influenced by the dietary variables of low quality, vegetable protein diets common to low income groups in the South, and calcium level. Diets that contained little animal protein and whose major protein source came from cereals and beans produced an imbalance of essential amino acids, poor iron utilization, and altered excretion of certain vitamins. When the same diet also included a low intake of calcium, a negative phosphorus and magnesium balance developed. The study also provided evidence that the present National Research Council's recommended daily allowance for protein for children are minimal and do not contain a sufficient margin of safety.

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Chemistry of Fructose

In studies of the basic chemistry of fructose, it has been determined that a solution of fructose contains three isomers. Unlike glucose, the distribution of the three isomers varies greatly with concentration and temperature. This variation complicates the use of fructose in food applications.

Basic studies have revealed the three isomers present in solution are the usual 6-membered ring form as found for crystalline fructose, and the two possible 5-membered ring forms. Study of the properties has shown that with increasing temperature, the concentration of the 5-membered ring forms increases and alters food properties such as water activity of the sugar and its sweetness and browning activity. By use of a gas chromatographic technique and computer analysis of the data, optical rotatory properties of all three fructose isomers have been described. Basic data such as these make it possible to understand the chemical behavior of fructose when added to food systems.

High fructose corn syrup (HFCS) promises independence from foreign sources of sugar. Basic data on the properties of fructose will allow food manufacturers to control sweetness, nutritive value, flavor, and energy values of HFCS-sweetened products over a broad spectrum, giving consumers greater discretion in choosing their food and beverage products.

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Hybrid Graft Polymers and Plastics

Basic studies on the free radical and other chemical combinations of organic and inorganic monomers with starch, leather, and other natural polymeric agricultural products have provided new classes of hybrid polymers, complex molecules, and plastics with a wide range and diversity of useful properties. Some of these unique materials have found commercial application. One such derivative, starch xanthate, can provide a means for slow release of pesticides, can be used to make powdered rubber by an energy-saving process, and one form of the substance can be used to reduce toxic levels of metals such as lead, zinc, silver, copper, and cadmium in industrial waste water. The combination of acrylonitrile and starch has produced a material—the so-called "super slurper"—that can fix large quantities of water in fluid-control applications, ranging from diapers and bandages to firefighting and sandy soils. Another grafting reaction, the combination of leather with a long chain amino acid, converts leather into a dry-cleanable product.

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Precombustion Pyrolysis

Studies of precombustion pyrolysis have defined the various chemical pathways by which heated wood degrades into simpler flammable and nonflammable substances before igniting. This knowledge has enabled chemists to devise more effective fire retardants by selecting chemicals that shift precombustion pyrolysis reactions in the direction of higher relative yields of nonflammable products.

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Fire Spread

Research on the mechanisms of fire spread in finely divided forest fuels led to the development of the first universally applicable prediction system for the rate of fire spread based on first principles of heat transfer. This model forms the basic framework for the National Fire Danger Rating System to optimize the effectiveness of the wildlands firefighting efforts of Federal and State agencies, a $250 million annual cost to the public.

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Principles for Mechanically Harvesting Fruits and Vegetables

Basic to the development of mechanized harvest systems for fruits and vegetables has been the study and understanding of such areas as the biophysical properties of selected fruits and vegetables, forces effecting detachment from tree or plant, detection of crop maturity, effect of mechanical forces on product quality, and chemicals to promote even ripening and reduce detachment forces. Such research has already led to the development of mechanical harvest systems for a number of fruit and vegetable crops.

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Control of Soil Structure

The possibility of managing intensively cultivated soils by application of polymer chemistry was demonstrated during the 1950's. A wider range of substances has become available, and there are now available materials that can stimulate seedling growth, reduce evaporative losses from soil, and ameliorate the severity of diseases. The potential exists for providing nitrogen and phosphorus bound to these polymers in time-release mechanisms that will improve their efficiency and reduce their propensity to be lost by leaching and surface erosion so as to cause eutrophication of nearby streams and lakes.

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Water Quality

Water standards identified in Section 208 of Public Law 92-500 require that increased emphasis be given to the environmental aspects of chemical behavior. Basic research on erosion, hydrology, sedimentation, and environmental behavior of agricultural chemicals and sediments has generated a large volume of data in recent years. These data are now being brought together and structured into mathematical models for predicting environmental transport of agricultural chemicals (pesticides and fertilizers) and sediments from agricultural lands, mine spoils, and other disturbed areas. Such models have potential applications for improving production and management practices for crops, as well as for meeting the mandates of Public Law 92-500.

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Systemic Insecticides

Recent innovations in molecular design of systemic insecticides have produced phloem mobile systemics (PMS) that pass through plant cell membranes, translocate with sugars, and concentrate in living phloem tissue. Because many forest insects feed on rapidly growing phloem tissue where the PMS is concentrated, much-reduced dosages of toxicants are needed for effective pest control. The necessary chemical structure for phloem mobility has been determined, and the practical effectiveness of one PMS has been demonstrated experimentally against the western spruce budworm. The PMS principle lends itself to development of chemicals that are innocuous until converted by plants into toxicants and is adaptable to other pesticides, e.g., fungicides, herbicides, animal repellents. These chemicals offer promise of greater specificity toward target pests and reduced hazards to humans and other

nontarget organisms in the environment.

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Chemical Properties of Wood

Basic research on the structures and reactions of the chemical components of wood has led to advances in the basic understanding of tree chemistry and to assessments of the potential of wood as a source of industrial chemicals. Major advances have been made in methods for characterizing and quantifying the carbohydrate, lignin, oleoresin, and extractive components in both hardwoods and softwoods.

The complex stereochemistry of numerous wood carbohydrates has been described, as has the significance of this molecular geometrical arrangement to chemical reaction kinetics. New phenolic compounds in hardwood heartwood extracts and new terpenoid components in pine bark extracts have been discovered and related to biogenetic processes. Synthetic chemical cellstressing can increase yields of oleoresins from pines without altering the basic chemistry of oleoresin production by the cell. Basic data have been developed on this biodegradation of lignocellulosic material by enzyme systems. This basic chemical research provides fundamental knowledge for understanding and improving pulping processes, preservative treatments, and chemical byproduct recovery from wood-processing plants.

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Wood Fiber Properties

Basic research related to wood fiber products has advanced the fundamental understanding of the papermaking process, making possible significant improvements in paper products. Wet strength is an important paper property. Moisture breaks interfiber bonds, thereby weakening the paper. It has been found that swelling action of wet fibers is a more significant factor in breaking interfiber paper bonds than is the direct bond displacement of solvation action of the water on the fibers. A formaldehyde treatment can block the entry of water into wood fibers, preventing initial swelling and preventing the rupture of interfiber bonds. Similarly, it has been found that fiber movement due to shrinkage during drying also ruptures bonds. Physical restraint (pressing) can sufficiently reduce fiber movements during drying to enhance paper strength.

Basic research studies in orienting or aligning fibers in paper, "unwinding" the individual wood fibers into their smaller microfibril structural components, also are pointing the way toward better paper materials. New discoveries in the field of ways to measure the basic physical properties of fibers and papers enable more rigorous engineering of paper product designs, making paper a vastly more useful and serviceable material of construction.

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Behavioral Chemicals for Insect Control

Behavioral chemicals are substances of plant or animal origin that function in orientation of insects to their hosts or in communication between individual insects. Pheromones are natural products of insects that function as chemical mediators of behavior and cause insects to aggregate at a food source or attract the opposite sex for mat-

ing. Because insects are highly sensitive and strongly attracted to minute concentrations of pheromones, these materials are especially useful for population survey and offer a unique opportunity for safe chemical control without harm to the environment.

Basic research on identification and synthesis of insect pheromones and rapid development of slow-release formulations and application techniques is stimulating the development of these substances for practical use. Pheromones are now available and in operational use for surveys, or are used in research for such major agricultural and forest insect pests as the European pine shoot moth, spruce budworm, Douglas-fir tussock moth, gypsy moth, southern pine beetle, smaller European elm bark beetle, boll weevil, Japanese beetle, tobacco budworm, house fly, mediterranean fruit fly, and the peach tree borer.

Continued development of behavioral chemicals for population assessment and control is complex and dependent upon a broadened base of basic research.

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General Equilibrium Models

A model of a national economy was produced in 1973 that was a significant advance on the model developed by Nobel Prizel winner Wassily Leontief. Leontief's model was shown to be a limiting case of the linearized Walras-Cassel model. The model was reformulated as a quadratic input-output model (QIO). For a 10 percent increase in government demand, the QIO model resulted in estimates of price inflation of 1.991 percent with a corresponding increase in real final output of only 0.146 percent with full employment of labor. In an unemployment situation, the rate of price inflation and growth of real final output were 0.783 percent and 1.312 percent respectively. For the conventional input-output model, all increased demand was reflected as growth in real final output of 1.972 percent. The new methodology is compatible with the simultaneous occurrence of increased price inflation and chronic high unemployment.

Other researchers have modified this work and adapted it to forecasting work in the dairy sector. (One version is now in a computer at Washington, D.C., and another at Pennsylvania State University, University Park, Pa.)

Harrington, David Holman. 1973. Quadratic Input-Output Analysis: Methodology for Empirical General Equilibrium Models. Lafayette, Ind., Purdue Univ., Ph.D. Thesis, Dec. 1973. 194 pp.

Spatial Equilibrium Analysis

There has been growing interest among economists in the explicit treatment of the spatial dimension of market prices of agricultural products. National aggregates of supply and demand have been refined to reflect the peculiar characteristics of subregions of the country. These regional measures have made it possible to conduct more sensitive analyses of alternative policy choices and market conditions than was possible with more highly aggregated relationships.

A powerful algorithm has been developed for analyzing spatially oriented market systems. It is extremely flexible in accepting demand and supply functions and as a part of a more complex system.

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Riley, John B. 1974. A reactive programming model for the fluid milk industry. Res. Rept. P-697, Okla. Agr. Exp. Sta., Stillwater, Oklahoma.

Seale, A. D. and M. B. Allen. 1960. An evaluation of the competitive position of the snap bean industry in Mississippi and competing areas. AEc Tech. Pub. No. 3, Miss. Agr. Exp. Sta. College, Miss. December 1960.

Takayama, T. and G. G. Judge. 1963. Non-linear formulations of spatial equilibrium models and methods for obtaining solutions. AERR 66, Ill, Agr. Exp. Sta. in cooperation with Farm Econ. Res. Div., ERS, USDA, Urbana, Ill.

Tramel, Thomas E. 1965. Reactive programming: An algorithm for solving spatial equilibrium problems. AEC Tech. Pub. No. 9, Miss. Agr. Exp. Sta., State College, Miss.

Zusman, Pinhas, Abraham Melamed and Itzhak Katzir. 1969. Possible trade and welfare effects of EEC tariff and "reference price" policy on the European-Mediterranean market for winter oranges. Giannini Foundation Monograph No. 24, California Agr. Exp. Sta., Berkeley.

Economics of Alternative Technologies and Management Systems in Livestock Production

An economist working cooperatively with animal scientists is developing production functions for various classes of beef cattle to reflect a variety of rations, management systems, and environmental conditions, and to identify efficient management systems from calf production to delivery of carcass beef. The heat increment of a cattle ration can be a boon in cold weather or a burden in hot weather. A conceptual framework has been developed that provides the basis for: (1) Formulating beef rations with different quantities of heat increment relative to net energy and (2) ascertaining the differences in animal performance between rations with different relative amounts of heat increment under specified conditions of environmental stress. Procedures were also developed for formulating such rations.

Brokken, Ray F. 1971. Programming models for use of the Lofgreen-Garrett net energy system in formulating rations for beef cattle. Jour. Animal Sci. 32:685-691.

Brokken, Ray F. 1971. Formulating beef rations with varying levels of heat increment. Jour. Animal Sci. 32:692-703.

Dinius, D. A., R. F. Brokken, K. P. Bovard, and T. S. Rumsey. 1976. Feed intake and carcass composition of angus and santa gertrudis steers fed diets of varying energy concentration. Jour. Animal Sci. 42:1089-1097.

Short-run Pricing in Commodity Markets

The strength of the U. S. economy derives from the ability of markets in the private sector to perform their classic intermediary role of allocating resources, goods, and services among buyers and sellers. Recent rapid movements in commodity prices emphasize the need for better understanding of this pricing process. This need is all the more urgent because of heightened state trading by major new customers such as the U.S.S.R. and the People's Republic of China.

In appreciation of this need, economists had already set out to gain a better understanding of pricing in commodity markets. They examined the statistical properties of the distribution of daily closing futures prices for corn, wheat, soybeans, soybean oil, soybean meal, shell eggs, frozen pork bellies, live cattle, Maine potatoes, and sugar. They found that commodity futures prices do not adjust efficiently to new information in the short run, but exhibit more or less regular patterns which are not directly the result of shifts in supply and demand. This lack of serial independence in price movements could be due to price manipulation by certain traders or the tendency for groups of traders, for whatever reason, to follow the same technical advice or the same charting procedures.

Mann, Jitendar S., and Richard G. Heifner. 1976. The distribution of shortrun commodity price movements. U. S. Dept. of Agriculture, Econ. Res. Serv., Nat'l. Econ. Analy. Div., Tech. Bul. No. 1536. 68 pp.

Paul, Allen B. 1976. Treatment of hedging in commodity market regulation. U. S. Dept. of Agriculture. Econ. Res. Serv., Nat'l. Econ. Anal. Div., Tech. Bul. No. 1538. 27 pp.

Theory of Market Density and Plant Size and Location

Important extensions of firm and industry theory have been developed that make market density a determinant of the size and location of industry operating units or plants. The theoretical approach for introducing market density into plant and industry models and analyses was developed in the late 1950's and early 1960's. Subsequently, others developed analytical techniques and further refined the theory. These advances have contributed significantly to our understanding of the workings of the total economy and particularly to our understanding of the location of economic activities; for example, the necessary size and density of an industrial-urban complex in order to be economically viable and the social costs of zoning restrictions that limit the density and location of economic activities.

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Chern, Wen-Shyong, and Leo Polopolus. 1970. Discontinuous plant cost function and a modification of the Stollsteimer model. Amer. J. Agr. Econ. 52:581-586.

French, B. C. 1960. Some considerations in estimating assembly cost functions for agricultural processing operations. J. Farm Econ. 42:767-798.

Fuller, S. W. and Monty Washburn. 1974. Measurement and analysis of variable inputs used in the cotton ginning process. New Mexico Agr. Exp. Sta. Res. Rep. 288.

Henry, W. R. and J. A. Seagraves. 1960. Economic aspects of broiler production density. J. Farm Econ. 42:1-17.

Hurt, Verner G., and Thomas E. Tramel. 1965. Alternative formulations of the transshipment problem. J. Farm. Econ. 47:763-773.

King, Gordon A., and Samuel H. Logan. 1964. Optimum location, number and size of processing plants with raw product and final product shipments. J. Farm Econ. 46:94-108.

Kloth, Donald W., and Leo V. Blakely. 1971. Optimum dairy plant location with economics of size and market-share restrictions. Amer. J. Agr. Econ. 53:461-466.

Ladd, George W., and M. Patrick Halvorson. 1970. Parametric solutions to the Stollsteimer model. Amer. J. Agr. Econ. 52:578-580.

Leath, Mack N., and James E. Martin. 1966. The transshipment problem with inequality restraints. J. Farm. Econ. 48:894-908.

Polopolus, Leo. 1965. A working model for plant numbers and locations. J. Farm Econ. 45:631-645.

Toft, H. I., P. A. Cassidy, and W. O. McCarthy. 1970. Sensitivity testing and the plant location problem. Amer. J. Agr. Econ. 52:403-410.

Warrach, Allan A., and Lehman B. Fletcher. 1970. Plant location model suboptimization for large problems. Amer. J. Agr. Econ. 52:587-590.

Williamson, J. C. 1962. The equilibrium size of marketing plants in a spatial market. J. Farm Econ. 44:953-967.

Water Rights in the West

Arid or semiarid conditions in the Western States have led to modification and, in some instances, repudiation of the riparian water-rights doctrine regarding the use of watercourses. Most of these States have an alternative body of law—the appropriation doctrine—and a few also have Pueblo water rights. Hawaii has unique water rights. Still other water law doctrines apply to certain ground water and other water sources.

Researchers have completed a comparative analysis of the development and status of the constitutional provisions, statutes, reported court decisions, and some administrative regulations and policies regarding water rights laws in the 19 Western States.

This work is reported in three volumes. Volume I deals with types and characteristics of watercourses, the property nature of water and water rights, water rights systems, and—in considerable detail—the nature, acquisition, and exercise of the appropriative water right. Volume II treats the riparian doctrine; the Pueblo water right; unique Hawaiian water rights; the protection, loss, adjudication, and administration of water rights in watercourses; diffused surface waters and other waters at the surface; and ground water rights. Volume III includes chapters on Federal-State relations, interstate matters, international matters affecting water rights, and summaries of the water rights systems in each of the 19 Western States.

Hutchins, Wells, A., Harold H. Ellis, and J. Peter Debraal. 1976. Water rights laws in the nineteen western states. U.S. Dept. Agr., Vol. III (in process).

Resource Ownership and Property Rights

Concepts of property rights and land use have been explicated by treating property rights as a communication system to be evaluated in terms of efficiency, equality, privacy, and freedom.

Specifically, interrelations among persons with respect to property constitute an information system. Through this system are transmitted messages such as recorded deeds, open and notorious possession, boundary markers, leases, oral declarations, and payment of taxes. The media are institutions such as markets, courts, law enforcement, and other administrative agencies and law offices. To the extent that the structure of property institution influences, maintains, and reinforces property rules and their interpretation, the medium does determine the message.

Thus, information may be contained and governed by rules of property. Patents, copyrights, and trademarks are forms of intellectual property which affect not only individual behavior, but the performance of an economy or society. Property, itself, can be viewed as an information system of right holders. So conceived, it is possible to cut across traditional legal compartments and examine the performance of the property system. The patent system is supposed to encourage inventiveness, but does it? The land title system is supposed to ensure efficient transfer and firm possession of land, but does it? This research has implications for the efficient utilization of resources in the production of food and fiber and for the observed inflation in the value of farmland.

Wunderlich, Gene. 1972. Perspectives on property: An introduction, perspectives on property. Gene Wunderlich and W. L. Gibson, eds. Penn State Univ., Inst. for Res. on land and water resources, University Park, Pa. pp. 1-8.

Wunderlich, Gene. 1973. Public costs and land records. Amer. Univ. Law. Rev. 22:333-368.

Wunderlich, Gene. 1974. Property rights and information. Annals of Amer. Acad. of Pol. and Soc. Sci. 412:80-96.

Human Capital Investment Decisions

Development of the concept of human capital has led to several promising lines of research by

agricultural economists. Studies explain the time pattern of creation and utilization of a stock of human capital. This process requires that the investor divide his time among three activities—present production, adding to personal capabilities for future production, and current consumption.

Other studies have inquired into such things as the division of time between schooling (investment) and production or the question of optimal length of schooling, the optimum mix of work and on-the-job training, and determinants of the time of retirement. Human capital stock models are being extended by examining the determinants of health.

Johnson, Thomas. 1970. A model for returns from investment in human capital. Amer. Ec. Review. 60:546-60.

Palmer, Steven Keith. 1976. An empirical investigation of the determinants of the length of full-time schooling. Unpublished dissertation, N. C. State University, Raleigh, N.C.

Sadik, Ali, T. 1975. Investment, work and consumption: A life cycle model. Unpublished dissertation, N. C. State Univ., Raleigh, N.C.

Wallace, T. D. and L. A. Ihnen. 1975. Full-time schooling in life cycle models of human capital accumulation. J. of Political Econ. 83:137-156.

Demand Theory

Even though demand theory has received great attention and has become very sophisticated, there are recent developments that appear to hold great promise in understanding the basic choices being made by consumers. The concept has been developed that commodities are demanded to the extent that a given commodity contributes to the attainment of several objectives. Thus food is desired for its nutritional attributes as well as its taste components.

This notion has given rise to a number of research projects that may influence future demand analysis. One is a general modeling of the approach. Another is directed to the nutritional and nonnutritional components of the demand for food items. An example of an additional application of this basic idea is the component-pricing of fluid milk and of soybeans.

Ladd, George W. and Veraphol Suvannunt. 1976. A model of consumer goods characteristics. Am. Jour. of Ag. Economics, 58:504-510.

Lancaster, Kelvin. 1971. Consumer demand: A new approach. Columbia Press, New York.

Prato, A. A. and J. N. Bagali. 1976. Nutrition and nonnutrition components of demand for food items. Am. Jour. of Ag. Economics. 58:563-567.

Measurement of Consumer Demand

The construction of models that investigate price and income effects on consumption of individual agricultural commodities as well as the interrelationships among related products made possible a new level of precision in the measurement of demand. Studies have provided new insights into the complexities of farm product price behavior, improved understanding of the forces at work to influence price fluctuations, and a more adequate base for evaluating agricultural price policy alternatives. These studies produced new procedures for weaving together modern demand theory and the latest econometric methods. Methods have been developed that provide the foundation for similar investigations in other countries and for continuing improvement in price and consumption models for a large number of products in the United States.

Brandow, George E. Interrelations among demands for farm products and implications for control of market supply. Pennsylvania Ag. Exp. Sta. Bulletin 680, University Park, PA. Aug. 1961.

Frisch, R. 1950. A complete schema for computing all direct and cross-demand elasticities in a model with many sectors. Econometrica, 27:177-196.

George, P. S. and G. A. King. 1971. Consumer demand for food commodities in the United States with projections for 1980. Giannini Foundation Monograph No. 26, California Agricultural Experiment Station, Davis, California.

Labor Supply

Past work has spurred the development of economic theory and modeling of the choices of individuals and household members between market and nonmarket activities. Many of the study approaches that have grown out of the so-called labor-leisure problem are in a stage of development that should shortly move to the analysis of policies affecting farm people. Three important areas in which recent advances have occurred are market supply of labor by the household members, farm-nonfarm division of the farmer's work time, and effects of human capital investment on farm productivity.

Barros, Geraldo Sant'Ana De Camargo. 1977. Asking wages, market wages, and the off-farm labor supply by farm operators. Unpublished dissertation, N. C. State University, Raleigh, N. C.

Becker, G. S. 1965. A theory of the allocation of time. Economic Journal. 75:495-517.

Chang, Seok Jung. 1976. An economic analysis of the adoption of new wheat varieties under uncertainty in Ferozepur District (India). Unpublished dissertation, N.C. State University, Raleigh, N.C.

Hsu, Chun-Yang, Forthcoming. Education, production and labor substitution in agriculture. Unpublished dissertation, N.C. State University, Raleigh, N.C.

Huffman, Wallace, E. 1976. The productive value of human time in U.S. agriculture. American Journal of Agricultural Economics 58: 672-683.

Sexton, Roger Neil. 1975. Determinants of multiple job-holding by farm operators. Unpublished dissertation, N.C. State University, Raleigh, N.C.

Welch, Finis. 1970. Education in production. Journal of Political Economy 78:35-69

Interorganizational Coordination

Several research studies focusing on the process of developing coordination among organizations have been completed. Research objectives included: (1) Description and measurement of the amount and kind of interaction among organizations possible at local, community, district, and State levels; (2) specification of the effect of levels of interorganizational relations upon the local community's effectiveness in meeting local needs; (3) specification of factors that lead to increased coordination among agencies; and (4) empirical studies on rural development agency systems, natural resource agency systems, health organizations, and low income systems.

Chiacharoen. 1974. Cooperative interaction and goal attainment among rural development organizations: a study in interorganizational relations, Ph.D. dissertation, Iowa State University.

Klonglan, G.E., C. L. Mulford and R. D. Warren. 1976. Moderating effects on the relationship between interorganizational relations and goal achievement. Paper presented at the Rural Sociological Society meetings. New York City.

Klonglan, G. E., S. K. Paulson and D. L. Rogers. 1972. Measurement of interorganizational relations: a deterministic model. Paper presented at the American Sociological Association meetings. New Orleans.

Klonglan, G. E., R. D. Warren, J. M. Winkelpleck and S. K. Paulson. Interorganizational measurement in the social services sector: differences by hierarchical level. Administrative Science Quarterly 21:675-687.

Molnar, J. J. 1976. The integration of interorganizational networks: domain consensus and interdependence in organizational dyads. Ph. D. dissertation, Iowa State University.

Mulford, C. L., G. E. Klonglan and J. Kopachevsky. 1974. Interorganizational relations and goal achievement. Paper presented at the Rural Sociological Society meetings. Montreal, Quebec.

Mulford, C. L., G. E. Klonglan, J. M. Winkelpleck and R. D. Warren. 1975. Creating interorganizational coordination: an orientation. Sociology Report 122B. Department of Sociology and Anthropology, Iowa State University, Ames, Iowa.

Paulson, S. K. 1974. Causal analysis of interorganizational relations: an axiomatic theory revised. Administrative Science Quarterly 9:319-337.

Rogers, D. L. 1969. Costs and benefit of alternative strategies for interagency coordination, Chapter 9 in Aspects of Planning for Public Services in Rural Areas, Edited by David L. Rogers and Larry R. Whiting. Ames, Iowa: NCRCRD. June.

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Rogers, D. L. 1974. Towards a scale of interorganizational relations among public agencies. Sociology and Social Research 59:61-70.

Rogers, D. L., and E. L. Glick. 1973. Planning for interagency cooperation in rural development. Report 45. Center for Agricultural and Rural Development. Iowa State University, Ames, Iowa.

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Rogers, D. L., and J. Molnar. Organizational antecedents of role conflict and ambiguity in top-level administrators. Administrative Science Quarterly, in press.

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Current and Future Research Emphasis

The Congress has explicitly charged the Agriculture Department and the cooperating federally funded State agricultural and forestry research organizations with responsibility for both basic and applied research necessary to achieve the Nation's agricultural research mission. Thus, these public agricultural research organizations have a clear mandate to identify and to implement areas of basic and applied research. As stated earlier, the research strategy of these organizations is to allocate available resources over time among the total array of researchable problems in the basic-applied research continuum in such a way as to make a maximum contribution to the missions.

The process of identifying the mix of problem areas to be funded is a complex one, and an explanation of the theoretical or operational process for identifying that mix is beyond the scope of this report. However, it is not difficult to identify those broad areas of science for which the publicly funded agricultural and forestry research organizations must accept a primary responsibility for ensuring that basic research is adequately supported.

Agricultural and forestry systems are primarily biological processes and environment based. Thus the biological sciences and those areas of the geophysical sciences that relate to the occurrence and control of the microenvironmental conditions within which biological processes of agriculture

and forestry occur are clearly broad areas of science for which the public agricultural and forestry research organizations must accept a primary basic research responsibility. Basic research in other broad areas of science are also appropriate to agricultural and forestry research when clearly identified as mission supportive or mission contributing.

The following examples are areas of science in which a basic research approach is required. Advances in knowledge in areas such as these are important to high priority thrusts in agricultural and forestry technology or to advances in institutional arrangements and in the quality of life in rural communities and homes. Necessary increases in total resources available to the publicly funded agricultural and forestry research organizations are assumed.

Nitrogen fixation. Adequate supplies of nitrogen are essential to crop productivity. Increased crop yields during the past 25 years have paralleled increased use of nitrogen fertilizer. For several reasons, including energy and economic costs, improved or alternate technologies for providing nitrogen to crops need to be developed. Research in this area should determine which of the symbiotic or associated nitrogen fixation processes can be modified to reduce genetic, physiological, and environmental barriers to providing nitrogen to crops. The possibilities include, among others, in-depth exploratory research on the catalytic mechanisms, control, and efficiency of nitrogenase and associated reactions; genetics of regulation and transfer of nitrogen-fixation genes; and physiological and agronomic studies of N_2-fixing microorganisms and their associated crop plants.

Photosynthesis. Since 95 percent of the dry weight of plants is a result of photosynthesis, studies on this process have high priority in efforts to improve crop productivity. The objective of these studies will be to determine the fundamental biology involved in increasing net photosynthesis and to obtain more efficient partitioning of the products of photosynthesis into food products of high nutritional value. Research will be expanded in three major sub-areas: (1) Identifying the aspects of photosynthesis that limit CO_2 input in natural environments, (2) determining the relationship of plant development to photosynthesis, and (3) developing new methodology for plant breeders to aid in identifying and incorporating improved photosynthetic efficiency into crops.

Genetic engineering for plants. The objective of these studies will be to determine those plant processes and characteristics that can be used by plant breeders in manipulating plant genotypes to increase crop productivity. Biochemists and plant physiologists must be brought into direct and active team participation with plant breeders and other scientists who work with the genetic and cultural improvement of crops. Studies in this area will utilize pollen cell and tissue culture techniques to accelerate genetic improvement of crop plants by (1) determining how to regenerate whole plants from the cultures obtained, (2) applying the principles of somatic cell genetics to understanding the growth of higher plants, (3) performing mass selective screeening for traits of agronomic value, (4) employing cultures for preservation of germplasm of vegetatively propagated species, (5) developing selection schemes to recover processes unique to higher plants, (6) increasing genetic diversity by inducing and recovering chromosome changes in somatic cells, and (7) developing innovative techniques of genetic engineering.

Recombinant DNA. Recombinant DNA techniques are used to join together segments of DNA from different sources in a cell-free system to form recombinant DNA molecules capable of infecting a host cell and replicating either autonomously or as an integral part of the host's genome. The objective of this research is to improve techniques for applying this method to organisms useful in agriculture. Extending the technique to protoplasts of higher plants and animals would be a significant scientific advance. The technique could be used to achieve any of the many objectives of breeding in those cases where traditional approaches are less efficient. Some possible applications include: (1) Improved nitrogen-fixing bacteria, (2) improved bacteria for ruminant digestion, (3) improved photosynthetic efficiency, (4) biological control of pests, (5) host resistance to pests, and (6) improved quality of basic foodstuffs.

Plant protection. Plant pests are a major limitation to high crop productivity. Progress in reducing pest losses has been impeded by the rapid obsolescence of available technology, by various changes in production practices, and by the continued penetration of pests of foreign origin. Future progress requires basic research on losses in production caused by pests and on adverse environmental effects resulting from pests and methods of combating them. Emphasis will be on pest insects, nematodes, weeds, and pathogenic microorganisms. The research will be directed toward (1) identifying and quantifying the basic biological and physical parameters of a particular pest system such as host-pest-parasite-environmental interactions and the dynamics of pest and competitor population levels, migration, and lifecycle; (2) characterizing the fundamental physiology, biochemistry, behavior, and systematics of pests and competitors; and (3) identifying mechanisms of plant susceptibility and resistance.

Respiratory and enteric diseases. Respiratory diseases are one of the most economically important limitations to efficient animal production. Control of the diseases is very difficult due to the complex etiology involving one or more pathogens and many environmental effects. Fundamental research is needed on: (1) The nature and inheritance of innate defense mechanisms of livestock and poultry species, (2) methods of effectively stimulating specific immunity, and (3) the contribution of environmental and behavioral stressors on the susceptibility of animals to disease. Enteric diseases, particularly in young animals, cause an estimated $1 billion annual losses in the United States. Diseases such as calf scours, transmissible gastroenteritis, swine dysentery, colibacillosis of all species, and salmonella are examples of the broad range of enteric diseases that threaten every animal producer. Basic research is needed to develop simple but efficient methods to diagnose the cause of the disease and to stimulate the cellular immune mechanisms in the neonate.

Hormonal control of growth and reproduction. Many aspects of the growth and reproduction of animals, plants, insects, and other organisms are regulated by hormonal growth substances. Understanding the nature of these controlling mechanisms, the causal agents, and their mode of action could provide keys to embryonic mortality, ovulation synchronization, and growth efficiency in animals; uniformity in growth and ripening of plants; and insect population control.

Physiological control of cellular growth in animals. Progress in analytical methodology now will permit greater in-depth study of cellular function and the physiological mechanisms regulating the cellular composition of tissue. The quantitative and qualitative aspects of meat and animal products as food relate primarily to the animal's ability to deposit the desired quantity and quality of protein, lipids, and other compounds in tissue.

Factors at the cellular level influencing rate and efficiency of synthesis of protein, lipids, and other compounds are poorly understood. Isolation and identification of the cellular constituents that regulate tissue synthesis and degradation and the distribution and quantity of lipid deposition is necessary to determine which mechanisms are amenable to control.

Human nutrition. Knowledge of the precise kinds, quantities, and balance of nutrients required for human health and productivity is seriously lacking—not only for persons living in an ideal environment, but particularly for persons subject to dietary, climatic, and other types of stress. Support provided by this program emphasizes (1) determining nutrient requirements for healthy people with varying needs such as those occurring at different ages, sex, and occupation, with particular emphasis on needs of high risk groups; and (2) identifying and evaluating factors affecting the biological availability and utilization of nutrients.

Basic properties of food systems. Fundamental knowledge is needed on model animal and plant food systems (fluid, semisolid, and solid) to understand the role of various components in the systems and the effects of component interaction on the physical, chemical, organoleptic, microbiological, nutritional, functional, and structural properties. Basic data are needed to establish improved criteria for the safety and wholesomeness of foods and food ingredients. Research should include development of new screening methods to identify potential carcinogens, mutagens, and/or naturally occurring toxicants. Knowledge regarding microbiological hazards is incomplete. Procedures for enumerating cells in processed foods may fail to quantitate thermally stressed cells or recovery cells.

Terrestrial and aquatic ecology as related to atmospheric transfer and precipitation systems. Historically, it was accepted that local ecology was dependent primarily upon local geophysical characteristics, water precipitation, humidity, temperature, and local human activities. It is now recognized that materials other than water are transferred in the atmosphere over long distances and that those materials can have an important ecological effect in the locale in which they are precipitated. Those atmospheric deposits may play an important positive role as supplemental plant nutrients, or they may be injurious to plants. Those precipitants from the atmosphere may also influence the health of man, domestic and wild animals, and aquatic life.

Atmospheric transfer and deposit of materials are to a large extent subject to control by man. Improved understanding of atmospheric transfer and precipitation systems and their effects upon the ecology of affected locales is needed. Social decisions about the composition and location of activities must reflect these second order or spillover costs and benefits. Since many of those spillover costs and benefits are transmitted to society through the land-based agricultural and forestry industries, basic research on the relationships of atmospheric transfer and precipitation systems to agricultural and forest ecosystems will contribute to the agricultural research mission.

Crop growth models. Mathematical models can be developed to describe crop response to environmental conditions at different stages of phenological development. Major emphasis is placed on

environmental management systems to counteract adverse responses. When these models are appropriately interfaced, crop yield prediction is improved.

Characterization of new pathogenic nucleic acid moieties. The discovery of viroids and mycoplasms as causative agents of viral diseases opens up new areas for research. The presence of any array of nucleic acid pathogens ranging from the naked viroid to the viral nucleoproteins and on to the more highly organized bodies of mycoplasms analogous to a primitive form of naked bacteroid cells presents a problem of differentiation and development of different approaches to therapy. The most reliable diagnostic device for mycoplasms is their response to highly specific antibiotics. The processes for biogenesis of this material and transmission of hereditary control must be resolved. Among this series of agents are some of the most pernicious and destructive pathogens.

Alternative sources of energy. Farm and forest operations must become more versatile in the use of energy. Capability is required to utilize multiple sources of energy in agricultural operations such as solar radiation, wind, coal, crop and forest residues, nuclear radiation, and oil, as well as other sources presently unknown. The biomass conversion of plant materials to energy requires concerted study. The energy potential of various plants requires study as does potential production of the most desirable biological materials.

Salt control of irrigation return flows. Under natural conditions, rainfall leaches salt below the root zone of native vegetation. If crops with deeper rooting patterns are planted, some provision to move the salt deeper must be made. Under irrigation, this means adding more water than is lost by evapotranspiration. If excess water is applied, the subsoil salt is leached into the stream. Methods to add only enough water to keep plants turgid and salt just below the roots will result in less salt returned to streams. This approach to water quality control is much more economical and attractive than chemical desalting.

Biomass productivity and fuel combustion efficiency. Producing the maximum amount of wood and other organic fibrous materials in the shortest time possible by closely integrated use of fast-growing improved genetic material, close spacings, application of intensive cultural practices, and total tree or crop plant harvesting and utilization requires a strong underpinning of basic knowledge. Forest biomass produced under intensive short rotation management is highly suitable for various wood-using industries and as basic raw material for energy production. Quantity and quality of material produced, energy trade-offs, and the economic alternatives of intensive short rotation management for maximizing biomass production are practical considerations as basic knowledge is put into use.

Opportunities of use of wood and other organic fibrous materials as an alternate fuel to natural gas and oil is highly dependent on obtaining maximum combustion efficiency. However, little is known about the refinements for improving this efficiency, particularly about the interrelationships of particle size, moisture content, and density as they relate to alternative combustion and fuel-handling techniques.

Combustion products and their photochemistry. The growing use of fire as a silvicultural practice, coupled with the increasingly stringent air quality standards requires in-depth exploration of the chemistry of wood combustion and variations in combustion products with species and burning conditions. Release of these combustion products into the atmosphere where they are subjected to radiation throughout the solar spectrum, as modified by atmospheric transmissivity, demands the production of new knowledge about these photochemical processes involving combustion products.

Wood structure and durability. Principles leading to improved performance and longer lasting materials must be better understood to help ensure adequate long-term supplies of the Nation's basic materials of construction. Additional information on the long-term loading characteristics of wood and wood structural components; on wood-insect relationships, wood-fungi relationships, and wood-fire relationships; and on the manipulation of tree physiology will eventually lead to effective combined wood treatment and wood construction systems that are efficient and reduce the needs for toxic chemicals and large energy inputs.

Nutrient gains and losses associated with intensive forest management. Intensive cultural practices in concert with improved utilization practices are expected to result in major changes in soil nutrient reserves over a wide range of forest sites. Nutrient gains can be achieved by artificial applications of fertilizers, use of nurse crops and introduction of nitrogen-fixing plants. Nutrient losses result from complete removal of forest biomass and from soil disturbances attributable to intensive site preparation, vegetation control, and other related practices. Better understanding of nutrient budget and nutrient cycling processes under various intensities of forest management over a wide range of soil and site conditions will help maintain needed forest characteristics.

Forest fire effects. It is necessary to be able to predict the effects of fire on many components of forest ecosystems. This includes relationships of plants or organisms to fire, especially their heat

sensitivity under varying ecological conditions. Time/temperature relationships can result in thermal damage to plant organs as well as to soil fauna and organisms. More needs to be known about the physiological effects of near lethal temperatures on plant functions such as respiration, translocation, growth substances, and enzyme reactions.

Chemical derivatives from wood. Wood, a mixture of organic polymers, can be used directly as an energy fuel; as a raw material for conversion into liquid, solid, or gaseous fuels; for conversion into chemical feedstocks to replace petrochemicals; and for conversion into human or animal feedstuffs. Naval stores, lignin, and carbohydrates could be potential new sources of organic chemicals at lower costs and with environmental side-benefits. Basic research will develop information on solvation, separation, derivatives, and reactions of these complex chemical constituents of wood.

Methodologies for measuring nontimber goods and services of forest and rangelands. Improved methodologies are needed for defining the supply potential for all the varied, interacting goods and services provided by forest and rangelands.

Consequences of and adjustments to price instability. These studies should enhance understanding of modern market structure and performance and form a basis for more accurate forecasts of commodity prices, market demand and supply conditions, and the incidence of benefits and costs resulting from price and output instability. This knowledge, in turn, should provide an improved basis for evaluating various public options for market intervention or stimulation.

New research will inquire further into the nature and sources of price and output instability in commodity markets and quantify changing relationships. The effects of this instability on the organization and structure of farming will be assessed. Relevant actions and optional adjustments of farmers will be analyzed. Contracting, diversification, and enterprise-sharing arrangements will be included in these analyses.

Comprehensive economic forecasting and projection models. Efforts to upgrade information on the near-term agricultural outlook and on long-run projections both to public and private decision-makers provide a continuing framework for basic research. Economists forecast prices, production, domestic use, and exports for individual commodities; and they make estimates for aggregates, such as farm income, the farm and retail price indexes, and food consumption. In connection with this, they seek an increasingly relevant conceptual context for such forecasts to enhance their reliability and more adequately define the limits to this reliability and the reasons for these limits.

Experimental approaches include prototype goal programming to estimate the competitive equilibrium situation due to U. S. domestic and export food and fiber requirements, with technology, resource availability, and methods of production and marketing as fixed factors. A short-term aggregate income and wealth simulator model consists of 53 ancillary relationships, 21 simultaneous equations, and 4 account identities. It forecasts components of the income accounts, balance sheet, and a sources and use of funds statement for the farm sector.

World food situation and country market studies. Uncertainty about future world markets, particularly in regard to major trade commodities such as grains and oilseeds, places a premium on upgrading the quality of economic research on foreign markets. Accordingly, economists are evolving an integrated system of individual country models to be used either separately or as a properly linked world trade model. In-depth studies and models for individual major countries and/or economically integrated groups of countries will be linked to U.S. models already operational and others being developed. The models will be used for intermediate-term projections—up to five years. The development of such a framework that includes parallel analysis of countries at varying stages of development and with various forms of government will necessarily involve a significant component of basic research. This work will backstop continuing forecasts of the world food situation.

Population and migration. Systematic inquiries into changes in population size, composition, and related residential characteristics, and analyses of alternative explanations of these changes are basic inputs to other studies that seek to relate manpower utilization and consumer or resident satisfaction to the degree of development of a community, area, or region and to the interrelationships between that area and the Nation. These analyses comprise some of the basic materials necessary for an understanding of national and related subnational development. Attainment of this understanding is necessary so that a range of programs for development or revitalization of communities or cities, for provision of cost-effective facilities and services, and for provision of a minimum income for all residents can be most effectively evolved and administered.

Regional and rural development. An improved understanding is needed of the significance of the rural or nonmetropolitan sector in the national and international economies and the interfaces with other subnational entities such as communities. Modeling work is a key approach to gaining

needed answers.

Economists and sociologists are also exploring improved ways of estimating the comparative social and economic attainments of various communities so that the most meaningful and objective sets of indicators of progress can be produced. Preliminary findings using principal component analysis demonstrate the feasibility of quantifying various dimensions of socioeconomic well-being at the county level.

Food, nutrition, and income. A general realization is emerging that some income assistance programs are likely to be needed even in a full employment economy without undue wage-price inflation. Thus, adequate basic analyses will be needed of the role of income assistance programs in national and rural development, in the national economy, and in the attainment of a minimum level of living by all citizens. Adequate public evaluation of alternative minimum income programs depends on objective analyses of the underlying economic effects of these programs.

Capital and credit. Farm production is increasingly specialized and capital intensive. To remain competitive, some farms must use larger amounts of land of rapidly increasing value and buy large amounts of nonfarm inputs. At the same time, the Federal Government, through the Rural Development Act of 1972 and other policy instruments, has encouraged nonfarm activities in rural areas. The population turnaround of the 1970's also involved a relative increase in the population of many nonmetropolitan communities. At the same time, we have had wage-price inflation and high unemployment. These changing circumstances place a premium on addressing issues relating to the provision of credit to rural people and institutions. Addressing these and related issues requires a basic understanding of the functioning and significance of rural credit markets in the context of national development and the associated advancement of the food and fiber industry and rural communities.

Impact assessments. The 1970's have seen increasing conflicts between national development and the maintenance of environmental quality and community well-being. One of the evident continuing public concerns is that of attaining adequate levels of output of food, natural fiber, and wood products at the same time as the Nation undertakes to protect and improve environmental quality and provide needed sources of energy.

Impact assessments depend in a large measure on conceptualizing key interrelationships that underlie the major trade-offs that must be considered. For example, studies are needed to devise improved methodologies for evaluating and interpreting effects of discontinuing a pesticide use. These need to encompass changes in cost of production and farm and forest income for typical situations. Additionally, in a broader context, they need to relate to economic implications for national farm and forest income, consumer prices, and foreign exchange earnings.

Organization and Management of Research Activities

Most of the Nation's publicly supported agricultural research is performed by the 4 major and 2 smaller research agencies in the USDA; 56 Agricultural Experiment Stations in the 50 States, Puerto Rico, Virgin Islands, Guam, and the District of Columbia; 19 schools of forestry; 16 land-grant colleges of 1890; and the Tuskegee Institute. This geographically decentralized agricultural and forestry research system has built-in responsiveness to a wide range of national, regional, State, and local problems. In general, research in the USDA is more heavily concentrated on problems of national and regional significance, but not exclusively. The research agencies of the USDA and the State Agricultural Experiment Stations historically have pooled ideas, manpower, and facilities in order to ensure a coordinated attack on problems common to several States or to a region. Cooperative research efforts are coordinated and implemented through joint planning sessions, workshops, reviews, and scientist-to-scientist contacts.

Organization and Management Within the Agricultural Research Service

The Agricultural Research Service (ARS) conducts basic, applied, and developmental research on the production of plants and animals; on the use and improvement of soil, water, and air resources; on the processing, marketing, safety, and use of agricultural products; and on rural housing and consumer services. Research is usually focused on national and regional problems of continuing significance.

For purposes of administration and management of its research programs, the Agricultural Research Service is organized into 4 regions and 26 areas, which include 7 large research centers administered as separate units. The research is located at 149 separate locations in the United States, Puerto Rico, and the Virgin Islands. Intramural research in 12 foreign countries is separately administered by an International Programs Division. The research centers have large aggregations of diversified expertise concentrated at two

animal disease centers, four regional research centers for utilization and processing, and the Beltsville Agricultural Research Center which covers nearly all of the Agency's research programs. Many of the ARS locations are at land-grant universities where ARS scientists have ready access to library and computer facilities and to scientists and engineers of other disciplines.

While the administrative and fiscal management of ARS is achieved through the organizational structure, the scientific management of the research is accomplished through the ARS management and planning system (MAPS). The heart of this system is 67 subject-matter national research programs (NRP's) into which the Agency's total research program is divided. Each NRP has a science-oriented coordinator in the Agency's National Program Staff. Research is planned, documented, reported, and reviewed within the framework of the technological objectives described for each NRP. Decisions to initiate, terminate, or redirect research activities, including basic activities, are frequently proposed by performing scientists themselves at research locations, or are recommended by line and program managers during the annual review process, or are based on recommendations by research workshops, review teams, or research planning committees involved in intra- and interagency coordination.

ARS has not conducted a competitive basic research grant program for several years; in constant dollars, the ARS budget has declined 12 percent since 1968 (see Table 4). However, ARS does maintain a small extramural research program primarily for the purposes of filling gaps and supplementing or extending intramural programs. Research proposals are solicited and funding provided by the specific intramural programs. Such extramural research may be either basic or applied depending on program needs.

Basic research is recognized as an inherent characteristic of the ARS research program. All types of research are incorporated in the Agency's mission-oriented programs on a justified need basis.

Organization and Management of State Programs Conducted in Cooperation With the Cooperative State Research Service

The Cooperative State Research Service (CSRS) provides the administrative mechanism of the USDA for providing financial support to the State Agricultural Experiment Stations (SAES), cooperating forestry schools, the land-grant colleges of 1890, and the Tuskegee Institute. CSRS maintains a headquarters staff to administer funds and provide a national focus for the separate stations and schools.

The State Agricultural Experiment Stations. There is one SAES in each of the 48 States (two each in two States) and one each in Puerto Rico, Guam, the Virgin Islands, and the District of Columbia—for a total of 56. In general, the experiment stations are associated with a land-grant college or university and thus are associated with and have access to total university expertise and facilities.

Research programs of SAES are funded in part and on a continuing basis by the USDA through its CSRS. Funds are appropriated to the Department under the Hatch Act with a congressional directive that annual appropriations be distributed to the SAES on a formula basis. There are minor matching-fund requirements and the Secretary of Agriculture is instructed to work with SAES to ensure that Federal funds are used productively and for the purpose for which they were appropriated. In most States, Hatch and other Federal funds account for well under one-half of total operating funds of the SAES. The remaining funds are provided primarily from State appropriations.

The basic unit of research in the SAES is the project, which is described later in this section. Prior approval of CSRS must be obtained in order that a project be eligible for support with Hatch funds. Annual or terminal project reports of research accomplishments and expenditures are made to CSRS for review and approval.

In addition to the above project information, a summary financial report is made to CSRS by each SAES for each fiscal year and must be approved by CSRS as meeting overall funding and expenditure requirements for Hatch appropriations. CSRS also convenes peer panels to perform periodic on-site reviews of major research program areas within each SAES. The primary purposes of these reviews are to assist the SAES in its program planning, evaluation, and development efforts and to fulfill the congressional mandate that the Secretary of Agriculture provide assistance to the SAES individually and promote and assist in coordinating the research programs of the several SAES.

The SAES is typically one of three divisions within the college of agriculture of an 1862 State land grant university. The other two divisions are the State agricultural extension service and the academic program in agriculture. Each of the three divisions is administered by a director, and the three directors are responsibile to the college dean.

The SAES is a continuing research-performing organization in its own right administered within the land-grant university. It bears the cost of sustaining its own scientific expertise, support per-

sonnel, and research facilities and equipment within the academic departments of the university. This is in contrast to many internal university research institutes and centers which either assist academic faculty in obtaining outside grants or which make grants to academic faculty from the institute's or center's own funds for support of research conducted by the academic faculty in departmental facilities provided and equipped by the academic program of the university.

The director of the SAES allocates to each department on a continuing basis funds for research support costs, including nonfaculty personnel costs. In total, those continuing departmental allocations are a high percentage of all continuing support funds available to the SAES. It is the responsibility of the department head to allocate those continuing support funds among departmental faculty annually for support of approved SAES projects, subject to periodic review and approval by the SAES director. The department head also reviews the needs of the faculty for supplemental support of their research on SAES projects and makes recommendations to the SAES for the funding of such needs from the director's reserves. In a typical college of agriculture, SAES funding accounts for 60 percent or more of total research and academic faculty salaries and 80 percent or more of total support costs of research and academic activities of the faculty.

In the short run, the SAES research project is the primary unit of research resource management within the academic department and within the SAES. The research effort of each faculty member paid and/or supported by the SAES is defined in one or more project outlines. A project typically has a duration of three to five years but is commonly of longer duration for projects that are predominately basic. Each project outline describes project objectives, justification for attacking the problem, the current state of knowledge and the status of other research in this and in closely related problem areas, research methods and procedures to be utilized in achieving the objectives, and resource requirements.

Various devices are used by the SAES director to help ensure faculty project proposals that are of high quality from a scientific point of view and that are devoted to priority problems of the SAES. The first device is liberal support of faculty involvement in the affairs of professional and scientific organizations. The second is a process of continuous communication among the director, the department head, and the faculty. A third device is planned involvement of SAES faculty in research program reviews and discussions with the users of research results. These users include representatives from the agricultural industry and rural communities and extension personnel. These reviews and discussions are devoted to content of the current research program and research needs of the SAES clientele. A fourth device is periodic reviews of the research program in major problem areas by teams of peer scientists, normally with CSRS assistance. A fifth device is active encouragement of and liberal support for faculty study in other research agencies and institutions.

The State Forestry Research Organizations. The McIntire-Stennis Act authorizes Congress to appropriate funds to the USDA for support of forestry research programs in designated State Forestry Research Organizations (SFRO). Like Hatch funds, McIntire-Stennis appropriations are distributed to the SFRO by formula. The funds may be expended only on projects approved by CSRS.

Overview by the USDA and program planning and resource management are essentially the same for the SFRO as that described in preceding paragraphs for the SAES. The principal difference is in the organization at the State level.

At the State level, the SFRO may be the SAES, another designated unit of the land-grant university, or a designated unit of another State university. Further, the individual who administers the SFRO is known as the McIntire-Stennis Administrative-Technical Representative. Except for these differences, organization and management of the SFRO is the same as described for the SAES. In fact, in many States the SAES is also the SFRO and the SAES director is the McIntire-Stennis Administrative-Technical Representative.

The 1890 Land Grant Universities and Tuskegee Institute. Agricultural research programs of the 1890 land grant universities and Tuskegee Institute are funded primarily through research grants from the USDA administered by its CSRS. Typically, some operating funds and the principal capital items at these institutions are provided by the institution, primarily from State appropriations.

The Federal grant funds are appropriated by the Congress expressly for support of these institutions under authority of Public Law 89-106. The USDA is directed to provide assistance to the institutions in developing research programs to further the purposes of the Department and to ensure that in each State the program is coordinated with that of the SAES.

The grant-funded program of the USDA is administered within each of these institutions by a coordinator employed by the institution. The coordinator provides assistance to individual faculty within the academic departments of the institution in developing research grant proposals and in meeting fiscal and performance requirements of the USDA. He also provides liaison between the USDA and the institution and between the institu-

tion and the SAES. Individual faculty grants are administered through regular academic units of the institution. Thus, the grant-funded program of the USDA is administered within the 1890 land grant institution essentially as an internal granting unit.

Organization and Management Within the Economic Research Service

The Economic Research Service (ERS) conducts social and economic research on issues that affect all facets of the food and fiber sector, use of our Nation's resources, economic growth, and quality of life in rural America including: Estimates of current resource use and availability, output and distribution of food and fiber, forecasts and projections of resource use and output, adjustments and performance in the food and fiber sector and rural America, and the impacts on all segments of society. Research is focused on national and regional problems of continuing significance.

Management. Research priorities are determined through interaction of ERS leaders with the Office of the Secretary, congressional committees, and other agencies and organizations. Subject matter emphasis and problem orientation stem from organization of the service into six program divisions with responsibility for these respective broad subject matter areas: National economic analysis, commodity economics, natural resource economics, economic development, foreign demand and competition, and foreign development. These divisions, in turn, manage some 50 contributing subject matter or program areas for such categories as inputs and finance in the food and fiber sector, transportation economics, dairy, developed countries, rural resources and environment, manpower and population studies, and consumer economics and demand analysis.

Research projects are conducted within and across program area and division lines in accordance with ERS priorities and the availability of needed research expertise. The research is conducted both in Washington, D. C., and at some 70 other locations throughout the United States. ERS typically also has some personnel overseas on special projects relating to agricultural development. ERS also works with Federal and State agencies, with SAES, 1890 colleges and the Tuskegee Institute, Regional Centers for Rural Development, and other organizations as appropriate. This joint work includes the development of priorities and methodology, data accession, and interpretation and analysis and other phases of research, whether basic or applied, as the need arises. For example, one ERS researcher has been stationed at the Johnson Space Center, Houston, Texas, to work on interpretation of remote sensing for use in crop yield estimation. Others may analyze and interpret data available at a State capital or county seat. Others may work with university faculty on conceptual and methodological developments. Some work with physical and biological scientists at various laboratories and field stations, including ARS regional laboratories.

This routine management system is supplemented by a series of special provisions. In the case of a need for a major change in priorities, special work groups or task forces may be convened to help define the need and recommend alternatives for action. They may include members of a management team, researchers from various divisions or program areas, and resource people from outside ERS.

At the beginning of each planning cycle, 5 percent of the budget and personnel ceilings are withdrawn from the divisions and reallocated on the basis of proposals for new research from the divisions. Budget reviews are held each quarter and reallocations are made as needed. In addition, approximately one-third of the program areas are formally reviewed each year by the administrator and deputy administrators. This review typically follows a review by people outside the agency who have a particular interest or expertise in the area in question.

Intramural and extramural research. The vast majority of the ERS program is conducted by ERS personnel. ERS has cooperative agreements with land grant and other universities and with consulting firms. These agreements are based on the ability of outside units to contribute to the ERS program because of their competitive advantage with respect to competence, location, or data services. Such outside activities are carefully planned to supplement activities within ERS.

A new program of support for research at U. S. universities was recently inaugurated by ERS. The Service has invited research proposals on 25 special issues believed suitable for a graduate student's dissertation. ERS expects to accept, on a competitive basis, about 10 proposals for work to begin prior to October 1, 1977. ERS will initiate a research agreement or contract with the institution, specifying the research product and the amount of reimbursement.

Recognition and funding of basic research. In ERS planning and program development, basic research is not separately identified nor does it receive special funding. However, many of the project and program plans contain objectives and methodological approaches that require basic research for their accomplishment. Priorities are set first on the basis of the economic and social significance of the problem addressed. Determinations

are then made as to the approaches and resources of money, people, and time required. From this process, basic research, including conceptual development, model building, and new methods of measurement, are devised to facilitate the larger effort.

Organization and Management Within the Forest Service

The Forest Service maintains a forestry research program to provide the scientific basis for the management, protection, and use of the Nation's renewable natural resources. In addition to close support of its own national forest and state and private forestry programs, Forest Service research results also support the needs of other Federal agencies, State agencies, industries, and private individuals—thereby providing a basis for better management of all of the Nation's forest and related range lands.

Forest Service research provides the knowledge to improve productivity of forest and related range resources, and protects them from fire, insects, disease, and other destructive agents. It advances multiple use through research on silviculture, wildlife habitat, watershed management, timber harvest engineering, forest products, endangered species, range management, environmental protection and enhancement, landuse planning, and urban forestry. Research in resource economics keeps supply and demand information current and improves efficiency of forestry and range practices.

Research is conducted through eight regional experiment stations, the Forest Products Laboratory, and the Institute of Tropical Forestry. There are about 940 scientists at 81 project locations throughout the United States, including Puerto Rico. Some 78 percent of these project locations are on or near university campuses, and two-thirds of these are in direct affiliation with forestry schools.

The research program of the Forest Service is planned through principles of public participation as called for in the Forest and Rangelands Resources Planning Act of 1974, and in conjunction with agriculture research planning of the USDA in close coordination with universities and other forestry research institutions.

Forest Service research is carried out by research work units, by R&D programs, and in a few instances by pioneering research work units which involve unusually competent scientists of proven excellence. Currently, there are 239 research work units, 6 R&D programs, and 7 pioneering research work units. Forest Service research is mission oriented with a significant proportion of the program devoted to basic research to provide a fundamental basis for application and development of new technology. Research is managed to provide a basis for development of sound land management policy and to solve the ever-changing problems faced by resource managers. It provides scientifically valid information and technology to solve current problems, and it conducts basic research to ensure that scientific breakthroughs will continue to allow an ever-improving forest technology in the years ahead. The Forest Service utilizes cooperative research agreements, research grants, and research contracts to support the ongoing research mission.

Competitive Grants Program for Mission-Oriented Basic Research

Public Law 89-106 is a general authorization for the USDA to fund research through grants to other research performing organizations to further the purposes of the Department. One of the important uses originally visualized for this authority was the funding of mission-oriented basic research; i.e., basic research in areas in which advances are identified as prerequisite to continuing advances in applied agricultural research and development and in agricultural technology.

In the decade plus since passage of the act, the P.L. 89-106 grants authority has been used to achieve other priority national needs; but a competitive grants program for mission-oriented basic research is now being initiated. The Executive budget for fiscal year 1978 provides P.L. 89-106 funds for competitive grants for mission-oriented basic research in four high priority areas of research to be funded initially. Those areas are photosynthesis, nitrogen fixation, genetic engineering for plants, and plant protection. The competitive grants will be open to the entire U. S. scientific community. The program has been developed to complement the existing in-house research of the USDA and cooperating State research organizations.

Specific plans have been developed for administration and management of the program. Provisions are included for planning and review at the policy level to ensure coordination of the effort with other public and private research programs and to ensure selection of high priority areas to be funded over time. Provisions are also made for peer scientist participation in screening grant proposals and in program planning and development so as to ensure active interest and participation by the scientist community and the scientific quality of the research.

DEPARTMENT OF COMMERCE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Submitted by Robert M. White, Administrator

NATIONAL BUREAU OF STANDARDS

Submitted by Jordan J. Baruch, Assistant Secretary for Science and Technology

MARITIME ADMINISTRATION

Submitted by Jordan J. Baruch, Assistant Secretary for Science and Technology

OFFICE OF TELECOMMUNICATIONS

Submitted by Jordan J. Baruch, Assistant Secretary for Science and Technology

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NOAA Mission

The National Oceanic and Atmospheric Administration's (NOAA) broad goals include: (1) The development and execution of a national program to ensure the effective identification, management, and conservation of marine resources for the economic and social good of the Nation; (2) the development and operation of a national system to monitor and predict weather and environmental conditions for protecting life and property, and to increase the efficiency and productivity of government, industry, and the individual; (3) the preservation and development of the Nation's coastal resources by assisting the States and other public agencies in the wise management of the land and water resources of the coastal zone; and (4) the provision of the basic maps, charts, surveys, and specialized data required for safe navigation and accurate location.

Specific detailed functions are listed below:

- Collect, communicate, analyze, and disseminate comprehensive data and information about the state of the upper and lower atmospheres, of the oceans and the resources thereof including those in the seabed, of marine and anadromous fish and related biological resources, of inland waters, of the earth, the sun, and the space environment.
- Prepare and disseminate predictions of the future state of the environment and issue warnings of all severe hazards and extreme conditions of nature to all who may be affected.
- Administer a national management program to preserve, protect, develop, and where possible restore or enhance the land and water resources of the coastal zones, including grants to the States and interagency coordination and cooperation, as provided by the Coastal Zone Management Act of 1972, as amended by P.L. 94-370 of 1976.
- Develop technology and carry out scientific and engineering data collection and analysis and other functions to assess, monitor, harvest, and utilize marine and anadromous fishery resources and their products.
- Provide maps and charts of the oceans and inland waters for navigation, geophysical, and other purposes; aeronautical charts; and related publications and services.
- Operate and maintain a system for the storage, retrieval, and dissemination of data relating to the state and resources of the oceans and inland waters including the seabed, and the states of the upper and lower atmospheres, the earth, the sun, and the space environment.
- Explore the feasibility of, develop the basis for, and undertake the modification and control of environmental phenomena.
- Administer a program of sea grant colleges and education, training, and research in the

fields of marine science, engineering, and related disciplines as provided in the Sea Grant Program Improvement Act of 1976.

- Perform basic and applied research and develop technology relating to the state and utilization of resources of the oceans and inland waters including the seabed, the upper and lower atmospheres, the earth, the sun, and the space environment, as may be necessary or desirable to develop an understanding of the processes and phenomena involved.
- Perform research and develop technology relating to the observation, communication, processing, analysis, dissemination, storage, retrieval, and use of environmental data as may be necessary or desirable to permit the Administration to discharge its responsibilities.
- Acquire, analyze, and disseminate data and perform basic and applied research on electromagnetic waves, as they relate to or are useful in performing other functions assigned herein; prepare and issue predictions of atmospheric, ionospheric, and solar conditions, and warnings of disturbances thereof; and acquire, analyze, and disseminate data and perform basic and applied research on the propagation of sound waves and on interactions between sound waves and other phenomena.

Definition of Basic Research

Basic research is concerned primarily with gaining increased knowledge or understanding of a subject; it includes exploration, experimentation, theoretical analysis, and recording of the new information discovered; it is not generally directed toward any specific practical application or the solution of operational problems.

This is to be contrasted with applied research, which is concerned primarily with finding a practical use of existing scientific knowledge or understanding, or discovering new knowledge, for the purpose of meeting a specific recognized need. It discovers new relationships, new methods, or new applications of known methods.

Role of Basic Research

NOAA recognizes the need for increased understanding in areas directly related to the mission of NOAA, as well as the need for solutions to practical problems. NOAA's policy is to conduct and support a research program that is balanced in regard to applied research and basic research that supports NOAA's mission.

NOAA performs basic research in the upper and lower atmospheres, the oceans and the Great Lakes, the space environment, and the sun to develop an understanding of the fundamental processes and phenomena. NOAA also performs basic research on electromagnetic waves to support other NOAA functions.

Examples of Basic Research

Noted below are the most significant projects involving basic research NOAA has carried out in the past 10 years.

Studies of the Equatorial Ionosphere, Electrojets, and Irregularities

Studies of the equatorial ionosphere began with the installation, at Jicamarca, Peru, of a large incoherent scatter radar facility. Although NOAA turned the facility over to the Peruvian Government in 1969 and removed NOAA personnel, NOAA's Aeronomy Laboratory has remained active in the study of the equatorial ionosphere and its motions by incoherent scatter techniques using the Jicamarca facility and smaller NOAA-developed portable Doppler radar equipment (Refs. 3, 4, 7, 10, 11); the study of the electron densities in the equatorial ionospheric E and F regions (Refs. 1, 2, 5, 13); the use of airglow observations to understand the equatorial ionosphere (Refs. 6, 9); and, more recently, the application of similar Doppler radar techniques to study irregularities and the electrojet in the auroral zone (Ref. 12). This program is continuing both in equatorial and auroral regions and has recently evolved into the study of neutral motions in the troposphere and stratosphere, mesosphere, and thermosphere using Doppler backscatter radar techniques and observation of the Doppler shifts of airglow lines.

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Geophysical Fluid Dynamics

The NOAA Geophysical Fluid Dynamics Laboratory (GFDL) has conducted a broad program of research on mathematical modeling of the general circulation of the atmosphere, the oceans, and the ocean-atmosphere system throughout the entire 10-year period. With one of the world's largest and fastest computers, GFDL scientists have investigated the dynamics of geophysical fluids over a wide range of time and space scales. The studies are comprised of research on the structure and circulation of planetary fluid systems—the troposphere, the upper atmosphere, and the oceans.

Below are papers and articles from 1968 through 1975. NOAA authors are italicized.

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13. *Manabe, S.*, Climate and the ocean circulation: I, The atmospheric circulation and the hydrology of the Earth's surface, Monthly Weather Rev., 739-774, 1969. (22.)

14. *Bryan, K.*, Climate and the ocean circulation: III, The ocean model, Monthly Weather Rev., 806-827, 1969. (20.)

Structure and Motion of the Oceans

This program investigates the structure, velocity, extent, and variation of nearshore and ocean currents in order to predict the measurement of water, heat, living resources, and pollutants. This work is an essential element in understanding the ocean's role in climatic variations. Investigations include: (1) studies of the time and space variations of currents and on the physical properties and chemical characteristics of nearshore and oceanic waters, utilizing current meters, drifting instrumented buoys, satellite imagery, tide gages, and water sampling devices; (2) studies using deep-sea pressure gages to investigate the various scales of motion in the ocean and the tidal modifications induced by the Continental Shelf; (3) measurement of exchange rates among the Gulf of Mexico, Caribbean Sea, and the Atlantic Ocean and of the coastal discharge and dispersion of pollutants.

Papers and articles on this subject follow:

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3. Jelesnianski, Chester P., "Bottom stress time-history" in linearized equations of motion for storm surges: Monthly Weather Review *98*, No. 6, 462-478.

4. McLeish, William, Spatial spectra of ocean surface temperature: J. Geophys. Res. *75*, No. 33. 6872-6877.

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9. Hanson, Donald V. and Maurice Rattray, Jr., Estuarine Circulation Induced by Diffusion: Journal of Marine Research 30, No. 3, 281-294.

Stimulation of Resonances and Nonlinear Theory of Turbulence in the Ionosphere

The first observations of the ionosphere by topside sounder satellites revealed heretofore unobserved resonances in the ionogram records. Scientists from the NOAA Aeronomy Laboratory explained theoretically and verified experimentally the mechanism for the stimulation of resonances near the natural plasma frequencies (Refs. 1-3).

NOAA's Aeronomy Laboratory has been active in the theoretical explanation of turbulence, irregularities, and nonlinear wave interactions in the ionosphere using nonlinear perturbed orbit theory (Refs. 1-4). Attention has recently shifted to the application of similar mathematical techniques to the fundamental theory of neutral atmospheric turbulence and waves.

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2. *McAfee, J. R.*, Topside ray trajectories near the upper hygrid resonance. J. Geophys. Res. 74, No. 26, 6403-6408, 1969. (21.)

3. *McAfee, J. R.*, Topside resonances as oblique echoes, J. Geophys. Res. 74, 802, 1969. (28.)

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5. *Weinstock, J.*, Turbulent diffusion, particle orbits, and field fluctuations in a plasma in a magnetic field, Phys. Fluids 11, 1977, 1968. (30.)

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7. *Skadron, G. and Weinstock, J.*, Nonlinear stabilization of a two-stream plasma instability in the ionosphere, J. Geophys. Res. 74, No. 21, 5113-5126, 1969. (20.)

Laboratory Measurements of Ion-Neutral Reactions

Laboratory techniques developed since 1962 in NOAA's Aeronomy Laboratory have led to most of the available data on ion-neutral reactions that control the ion composition of the Earth's ionosphere and also the ionospheres of Mars and Venus. The principal technique developed, called the Flowing Afterglow Technique, has been widely copied in other laboratories where, in addition to its contributions to aeronomy, it is playing a valuable role in chemical kinetics generally, supplying reaction rate constants and thermochemical data for inorganic and organic systems. The flowing afterglow, originally capable of measuring reaction rates at room temperature only, was fashioned to operate from 80° to 900°K (Ref. 2), the widest range of temperature yet achieved by any method. Recently the experimental technology has been extended by the development of the so-called Flow-Drift tube, the combination of a flowing afterglow system with a drift tube (Ref. 15); this allows the energy dependence of ion-molecule reactions to be measured from 300° to several electron volts relative to ion kinetic energy. The ion-molecule reaction rate continues but emphasis has shifted to the measurement of neutral reaction rates important in the hydrogen, nitrogen, chlorine, and sulfur chemistry cycles of the stratosphere.

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2. *Dunkin, Fehsenfeld, Schmeltekopf, and Ferguson*, Ion molecule reaction studies from 300 to 600°K in temperature controlled flowing afterglow system, J. Chem. Phys., 1968. (97.)

3. *Schmeltekopf, Ferguson and Fehsenfeld*, Afterglow studies of the reactions of He^+, He_2S, and O^+ with vibrationally excited N_2, J. Chem. Phys., 1968. (92.)

4. *Ferguson, Fehsenfeld and Schmeltekopf*, Flowing afterglow measurements of ion-neutral reactions. Chapter of book Advances in Atomic and Molecular Physics, Academic Press, 1969. (83.)

5. *Fehsenfeld and Ferguson*, Origin of water cluster ions in the D region, J. Geophys. Res., 1969. (57.)

6. *Schmeltekopf and Fehsenfeld*, De-excitation rate constants for helium metastable atoms with several atoms and molecules, J. Chem. Phys., 1970. (53.)

7. *Ferguson and Fehsenfeld*, Water vapor ion cluster concentrations in the D region, J. Geophys. Res. 1969. (51.)

8. *Fehsenfeld, Dunkin, and Ferguson*, Rate constant for the reaction of CO_2 with O, O_2, and NO; N_2 with O and NO; and O_2 with NO, Planet. Space Sci., 1970. (51.)

9. *Ferguson*, Thermal energy ion-molecule reactions, Chapter in book Advances in Electronics and Electron Physics, 1968. (47.)

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15. *McFarland, M. Albritton, D. L., Fehsenfeld, F. C., Ferguson, E. E., and Schmeltekopf, A. L.,* Flow-drift technique for ion mobility and ion-molecule reaction rate constant measurements II. Positive ion reactions of N^+, O^+, and N^+_2 with O_2 and O^+ with N_2 from thermal to 2eV, J. Chem. Phys. 59. No. 12, 6620-6628, 1973. (33.)

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24. *Henderson, W. R.,* Fite, W. L., and Brackmann, R. T., Dissociative attachment of electrons to hot oxygen, Phys. Rev. 183, 157, 1969. (24.)

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Remote Sensing Techniques, Temperature Sensing, Optical Scintillations

The NOAA Wave Propagation Laboratory, at the inception of NOAA, was oriented toward research on the effects of the environment on the propagation of electromagnetic waves. Through the past 10 years, the orientation has been reversed in order to undertake research concerning the use of the effects on acoustic and electromagnetic waves to probe the atmosphere and the oceans, i.e., remote sensing (Ref. 1). The development of the acoustic sounder (Ref. 2), pulse Doppler weather radars, the FM-CW Doppler radar and the Doppler lidar have been notable accomplishments (Ref. 3). The emphasis is now shifting from instrument development toward the use of these remote sensing instruments and their unique capabilities for research toward a better understanding of the geophysical environment.

Mathematicians in NOAA's Wave Propagation Laboratory have had a continuing interest in the mathematical techniques for the retrieval of atmospheric temperature profiles from observations of the infrared emission of the atmosphere at several wave lengths emitted from different atmospheric depths. The techniques have had application to the remote sensing of atmospheric temperature profiles from satellites (Refs. 4, 5, 6).

The Optical Propagation Group at NOAA's Wave Propagation Laboratory, originally interested in the effect of a turbulent atmosphere on the propagation of light, has applied this knowledge to remote sensing of atmospheric winds and turbulence and, most recently, rainfall rate and raindrop site distribution by means of optical beams as viewed in the forward propagation direction. As well as the experimental work, the group has made major progress in developing and extending the theory of scintillations in a turbulent medium, including the explanation of the saturation effect of optical scintillations (Refs. 7-12).

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1. *Derr, V. E.,* Remote Sensing of the Troposphere, Ed., CU/NOAA Course Textbook, 1972. (Number of citations: 54.)

2. *Little, C. G.,* Acoustic methods for remote probing of the lower atmosphere, Proc. IEEE, 571-576, 1969. (32.)

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9. *Lawrence, R. S., Ochs, G. R. and Clifford, S. F.*, Measurements of atmospheric turbulence relevant to optical propagation, JOSA, 826-830, 1970. (23.)

10. *Ochs, G. R.*, Bergman, R. R. and Snyder, J. R., Laser-beam scintillation over horizontal paths from 5.5 to 145 km, JOSA, 231-234, 1969. (23.)

11. *Clifford, S. F.*, Temporal-frequency spectra for a spherical wave propagating through atmospheric turbulence, JOSA, 1285-1292, 1971. (22.)

12. *Clifford, S. F., Bouricius, G. M. B., Ochs, G. R. and Ackley, M. H.*, Phase variations in atmospheric optical propagation, JOSA, 1279-1284, 1971. (20.)

Plate Tectonics

Scientists with the marine geophysics program, in the Atlantic Oceanographic and Meteorological Laboratories, were among the very early proponents of plate tectonic theory and continental drift, particularly in the use of ocean bottom and continental shelf topography to make detailed fits of the present continents into the proto continent, Pangaea, prior to breakup.

Listed below are pertinent papers and articles (1968-1975). NOAA authors are italicized.

1. *Dietz, R. S. and Holden, J. C.*, Reconstruction of Pangaea: Breakup and dispersion of continents, Permian to present, J. Geophys. Res., 4939-4950, 1970. (Number of citations: 157.)

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6. *Freeland, G. L. and Dietz, R. S.*, Plate tectonic evolution of Caribbean-Gulf of Mexico region, Nature, 20-23, 1971. (28.)

7. *Dietz, R. S. and Sproll, W. P.*, Fit between Africa and Antarctica: A continental drift reconstruction, Science, 1612-1614, 1970. (23.)

8. *Grim, P. J.*, Connection of the Panama fracture zone with the Galapagos rift zone, eastern tropical Pacific, Marine Geophys. Res. 85-90, 1970. (21.)

Subprograms of the Global Atmospheric Research Program—GATE, BOMEX

The Barbados oceanographic and meteorological experiment (BOMEX) was a large-scale air-sea interaction field experiment conducted in the vicinity of the island of Barbados in late spring and early summer of 1969 and involved the coordinated talents and resources of Federal agencies and academic institutions. The primary objectives were to study the total ocean-atmosphere system within a limited oceanic area and to develop a pilot field study that may be used for planning and executing similar experiments in the future within the framework of the long-range global atmospheric research program (GARP) of the 1970's.

Field work for the GARP Atlantic tropical experiment (GATE) in the eastern tropical North Atlantic was completed in 1974 in collaboration with many national and international research groups. The objectives were to define the small-scale convection and other processes occurring in the atmosphere and upper ocean, and to parameterize these phenomena in large-scale atmosphere and ocean circulation models.

Papers and articles on BOMEX are listed below:

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2. Delnore, Victor E., "Diurnal Variation of Temperature and Energy Budget for the Oceanic Mixed Layer during BOMEX," *J. Phys. Oceanogr.*, Vol. 2, pp. 476-486 (1972).

3. Holland, Joshua Z., "Comparative Evaluation of Some BOMEX Measurements of Sea Surface Evaporation, Energy Flux and Stress," *J. Phys. Oceanogr.*, Vol. 2, pp. 476-486 (1972).

4. Holland, Joshua Z., and Eugene M. Rasmusson, "Measurements of the Atmospheric Mass, Energy, and Momentum Budgets over a 500-Kilometer Square of Tropical Ocean," *Mon. Wea. Rev.*, Vol. 101, pp. 44-55 (1973).

5. Jalickee, J. B., and E. M. Rasmusson, "An Atmospheric Budget Analysis Scheme," *Proc. Third Conf. Probability and Stat.*, Amer. Meteorol. Soc. (1973).

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Papers and articles on GATE are listed below:

1. Aspliden, C. I., Y Tourre and J. B. Sabine 1976: Some Climatological Aspects of West African Disturbance Lines during GATE. *Monthly Weather Review*, Volume 104, No. 8, pp. 1025-1029.

2. Burpee, R. W., 1975: Some Features of Synoptic-Scale Waves Based on a Compositing Analysis of GATE Data. *Monthly Weather Review*, Volume 103, No. 10, pp. 921-925.

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7. Merceret, F. J., 1976: Airborne Hot-Film Measurements of the Small-Scale Structure of Atmospheric Turbulence During GATE. *Journal of Atmospheric Sciences*, Volume 33, No. 9, pp. 1741-1746.

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10. Young, J. A., 1976: Wind Observations from the USNS VANGUARD during GATE Phase I. *Monthly Weather Review*, Volume 104, No. 3, pp. 316-320.

Climate Effects of Atmospheric Aerosols and Pollutants on Global Temperature

NOAA's climate research is pursued primarily through theoretical studies, empirical analyses, and numerical simulation. Research activity included the analysis of the 15-year global atmospheric data set from 1958 to 1973 to provide a definitive determination of interannual climate variability and to relate local anomalies such as droughts to anomalies in the surface temperature and in the snow and ice cover. One part of the program deals with the measurement and prediction of atmospheric carbon dioxide, whose inexorable increase may lead to significant global warming within the next 25 to 50 years unless projected fossil fuel combustion rates are radically reduced.

Pertinent papers and articles are listed below:

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5. *Climatic Effects, Impacts of Climatic Change on the Biosphere*, "Wheat" by Ramirez, J. N., C. M. Sakamota and R. E. Jensen, Section 4.1.2 CIAP Monograph 5, Part 2, Department of Transportation, Washington, D.C., pp. 4-37 to 4-90, September 1975.

6. J. Murray Mitchell, Jr., *An Overview of Climatic Variability and Its Casual Mechanisms*, University of Washington, Quaternary Research 6, 481-493, September 1976.

7. J. Murray Mitchell, Jr., *A Reassessment of Atmospheric Pollution as a Cause of Long-Term Changes of Global Temperature*, S. Fred Singer (ed), The Changing Global Environment, 149-173, D. Reidel Publishing Company, Dordrecht, Holland, 1975.

8. J. Murray Mitchell, Jr., *Observed Variability of the Climatic System*, WMO GARP Publication Series, No. 16, pp. 4-12, April 1975.

9. J. Murray Mitchell, Jr., *Note on Solar Variability and Volcanic Activity as Potential Sources of Climatic Variability*, WMO GARP Publication Series, No. 16, 127-131, April 1975.

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The International Field Year of the Great Lakes (IFYGL)

IFYGL was a joint American-Canadian contribution to the International Hydrologic Decade. The major purpose of the joint study was to develop a scientific basis for water resource management on the Great Lakes as an aid in solving problems of water quantity and quality. Lake Ontario was selected as a representative lake. A series of studies on the hydrology, physics, chemistry, and biology of the lake as well as investigations of the effects of ice and lake storms provide information necessary to help make sound management decisions relating to navigation, hydropower, public water supply, waste disposal, recreation, fish productivity, highway transportation, and the operation of port facilities. IFYGL emphasized the interrelationships between the currents and thermal structures and the chemical and biological processes.

Papers and articles by NOAA authors or by authors supported by NOAA funds appear below:

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Momentum and Water Vapor over Lake Ontario," *Journal of Physical Oceanography*, Vol. 5, No. 3, July 1974, pp. 532-540.

2. Csanady, G. T., "The Coastal Boundary Layer in Lake Ontario: Part II, The Summer-Fall Regime," *Journal of Physical Oceanography*, Vol. 2, No. 2, 1972, pp. 168-176.

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11. Jalickee, John B., Jason K. S. Ching, and James A. Almazan, "Objective Analysis of IFYGL Surface Meteorological Data," *Proc. 17th Conf. Great Lakes Research 1974*, pp. 733-750.

12. Chen, W. Y., "Effect of Non-Stationarity of the Wind Field on Values of the Drag Coefficient," Paper presented at *20th Conf. on Great Lakes*, Ann Arbor, Michigan, May 1977.

Hurricanes, Convective Clouds, Precipitation Processes

The weather modification research program conducted by NOAA is aimed primarily at developing a sound, scientific basis for practical weather modification through theoretical studies, laboratory investigations, computer modeling of severe storms and convective cloud processes,and confirmation by experimental field projects. The effort concentrated on: (1) Mitigation of damage caused by hurricanes and severe convective storms including extratropical cyclonic systems; (2) the modification of convective clouds in a subtropical environment (Florida) to increase rainfall; and (3) research on the physics and chemistry of cloud and precipitation processes.

Pertinent papers and articles appear below:

1. Anthes, Richard A., The role of large-scale asymmetries and internal mixing in computing meridional circulations associated with the steady-state hurricanes: Monthly Weather Review *98*, No. 7, 521-528.

2. Gentry, R. Cecil, Hurricane Debbie modification experiments, August 1969: Science *168*, April 24, 473-475.

3. Woodley, William L., Precipitation results from pyrotechnic cumulus seeding experiment: Journal of Applied Meteorology 9, No. 2, 242-257.

4. Black, Peter G., H. V. Senn, and C. L. Courtright, Airborne Radar Observations of Eye Configuration Changes, Bright Band Distribution, and Precipitation Tilt during the 1969 Multiple Seeding Experiment in Hurricane Debbie: Monthly Weather Review *100*, No. 3, 208-217.

5. Gentry, R. Cecil, Project STORMFURY: Bull. Am. Meteorol. Soc. *50*, No. 6, 404-409.

6. Simpson, Joanne, and Victor Wiggert, Models of precipitation cumulus towers: Monthly Weather Review *97*, No. 7, 471-489.

7. Scott, W. D. and Zev Levin, The effect of potential gradient on the charge separation during interactions of snow crystals with an ice sphere: Journal of Atmospheric Sciences *27*, No. 3, 463-473.

8. Gentry, R. Cecil, Tetsuya T. Fujita, and Robert C. Sheets, Aircraft, spacecraft, satellite and radar observations of Hurricane Gladys, 1968: Journal of Applied Meteorology *9*, No. 6, 837-850.

Thermospheric Studies

Studies of the neutral composition, ion composition, and temperature of the thermosphere have been carried out by the NOAA Aeronomy Laboratory using ground-based airglow observations (Refs. 2, 3). Solar occultation by the earth as seen from a satellite (Ref. 4) and theoretical chemical analysis (Ref. 1) have been carried out since 1968, and the satellite and airglow studies are continuing.

Pertinent papers and articles (1968-1975) are referenced below. NOAA authors are italicized.

1. *Norton* and Barth, Theory of nitric oxide in earth's atmosphere, J. Geophys. Res., 1970. (Number of citations: 54.)

2. *Norton, R. B.* and Findlay, J. A., Electron density and temperatures in the vicinity of the 29 September 1967 middle latitude red arc, Planetary Space Sci. 17, 1867-1877, 1969. (29.)

3. *Noxon, J. F.* and Johanson, A. E., Changes in thermospheric molecular oxygen abundance inferred from twilight 6300A airglow, Planetary Space Sci. 20, 2125-2151, 1972. (23.)

4. Roble, R. G. and *Norton, R. B.*, Thermospheric molecular oxygen from solar extreme-ultraviolet occultation measurements, J. Geophys. Res. 77, No. 19, 3524-3533, 1972. (21.)

Other Projects

In addition to the most significant projects listed previously, NOAA has conducted research in other areas during the past 10 years which, although highly cited, has not evidenced a coherent history of citations. These papers, published since

1968, and having total citations of 30 or more for the period 1968-1975 are listed below. NOAA authors are italicized.

1. Utlaut, W. F. and *Cohen, R.*, Modifying the ionosphere with intense radio waves, Science, 254-255, 1971. (Number of citations: 46.)

2. Kane, S. R. and *Donnelly, R. F.*, Impulsive hard x-ray and ultraviolet emission during solar flares. Astrophysics J. 164, 151-163, 1971. (38.)

3. *Simpson, J. and Wiggert, V.*, Models of precipitating cumulus towers, Monthly Weather Rev., 471-489, 1969. (38.)

4. Hansen, R. T., Garcia, C., Hansen, S., and *Loomis, H. G.*, Brightness variations of the white light corona during the years 1964-67, Solar Physics, 1969. (35.)

5. *Bailey, D. K.*, Some quantitative aspects of electron precipitation in and near the auroral zone, Rev. Geophys. 6, No. 3, 289-346, 1968. (34.)

6. McManus, D. A., *Burns, R. E.* et al., Regional aspects of deep sea drilling in the Northeast Pacific, Initial Report of Deep Sea Drilling Project 5, 1970. (32.)

7. *Williams, D. J., Fritz, J. A.*, and Konradi, A., Observations of proton spectra and fluxes at plasmapause, J. Geophys. Res. 78, No. 22, 4751-4755, 1973. (31.)

8. *Kessler, E.*, On the distribution and continuity of water substance in atmospheric circulations, Meteorological Monograph 10, 1-84, 1969. (31.)

9. *Cohen, R.* and Whitehead, J. D., Radio-reflectivity detection of artificial modification of the ionospheric F layer, J. Geophys. Res. 75, No. 31, 6439-6445, 1970. (30.)

Current and Future Research Emphasis

The most significant NOAA projects involving basic research that are currently in progress are discussed below.

Climate. The climate of the Earth is simulated through the use of a new global general circulation mathematical model to determine the model's capability for simulating the distribution of cloud cover and radiative flux in light of recent observations from meteorological satellites. The model will also be employed for simulations based on boundary conditions obtained from paleoclimatic reconstructions of 18,000 years ago.. Mathematical atmospheric circulation models will be applied to the study of the natural variability of climate and to the study of the stability of climate under external stimuli, including the photochemical interactions of ozone with the dynamical circulation and the variation of carbon dioxide involving the buffering of carbon dioxide by the biosphere and the oceans.

Chemistry, physics, and dynamics of the stratosphere. A comprehensive study of the chemistry, physics, and dynamics of the stratosphere involves: (1) Global measurements of the concentrations of stratospheric constituents to obtain their temporal and spatial distributions; (2) laboratory measurements of chemical and photochemical reaction rates of stratospheric constituents; (3) numerical models of the stratosphere including one- and two-dimensional models emphasizing dynamics; and (4) remote measurements and data analysis of small-scale stratospheric dynamics including turbulence and diffusion.

Solar-terrestrial physics. Theoretical and experimental research studies are conducted to understand the fundamental physical processes responsible for and causing: (1) The observed energy release in the form of electromagnetic and particle radiation at the solar surface during solar disturbances; (2) the propagation of this energy through the interplanetary medium to the near-earth environment; (3) the transfer of this energy from the near-earth interplanetary medium into the Earth's magnetic field, the magnetosphere; and (4) the behavior and subsequent effects of this energy within the magnetosphere, the ionosphere, and upper atmosphere regions.

Severe storms research. Studies are underway on the circulation of severe storms and tornadoes, including the origin and fate of storm energy and the numerical modeling of dynamical, thermodynamical, microphysical, and electrical processes within severe storms.

Structure and motion of the oceans, continental shelf processes. Investigations of the structure, velocity, extent, and variation of nearshore and ocean currents; the time and space variations of currents; and the physical properties and chemical characteristics of nearshore waters are continuing. The continental shelf and open ocean tides are being studied through the use of deep sea tide gage data and comprehensive satellite tidal data. Studies into the behavior and dispersion rate of geographic change and sediment onto the ocean floor of man-induced matter, and the origins and distribution of major physiographic features on the continental shelf are continuing.

Geodetic studies. The relationships between vertical changes of the land mass in tectonically active areas and observed tidal changes, and between elevation and gravity changes in tectonically active areas of the United States are being studied. Use of satellite radar altimeter data is being used to determine nature of geoidal fluctuations over marine features such as the shelf-slope break, seamounts, island chains, etc. Comprehensive research is underway to determine the rate of uplift in tectonically active areas such as the "Palmdale Bubble" of California and the Aleutian Island arc system. A formulation of geodetic

theory in terms of three-dimensional differential geodesy is being developed, as well as studies on the downward continuation of the geopotential and on a representation of the geopotential by density layering.

Global atmospheric research program/the global weather experiment (FGGE). This experiment has four basic objectives: (1) To obtain a better understanding of atmospheric motions for the development of realistic models for extended range forecasting, general circulation, and climate; (2) to assess the ultimate limit of predictability of weather systems of various sizes and time scales; (3) to develop new methods for assimilation of meteorological data in numerical weather forecast models, and in particular, for using more effectively satellite data in the models; and (4) to design an optimum composite global observing system for routine numerical weather prediction on a global basis.

Air-sea interaction. The energy and moisture exchange between the ocean and atmosphere is basic to worldwide weather and climate and to the major ocean currents. Effort is directed toward the development of mathematical models of the exchange processes, major field investigations to provide data on the exchange processes, and modeling of storm surge flooding of coastal areas.

Tidal research. At the present time, NOAA is conducting a research project to evaluate the response method in comparison to other methods of tidal analysis. A second project has been the collection of offshore tidal data with deep-sea tide gages for application to continental shelf tidal modeling. A major application of future offshore tidal measurements by the Oceanographic Division will be the determination of offshore tides by a combination of satellite altimeter tidal data and *insitu* tidal measurements.

NOAA research priorities for the next 3 to 10 years include the following:

Oceans. These include: Understanding the role of the oceans in climate variation; continued development of numerical models of atmospheric and ocean systems over a wide range of spatial and temporal scales; and understanding the transport and chronic effects of pollutants on the ocean ecosystem.

Mesoscale weather. Short and medium range forecasting techniques are sought for severe weather and specialized users (e.g., agricultural weather); on the longer term, emphasis is on long-range forecasting. Improving the observation and modeling of mesoscale weather phenomena; obtaining a comprehensive description of severe storms, particularly tornadic storms; basic cloud and precipitation microphysics; and modeling the planetary boundary layer over irregular terrain are other areas of interest.

Geochemical cycles. This planned research emphasizes: (1) Understanding the geochemical cycles of carbon dioxide and nitrogen in the atmosphere, oceans, and biosphere; and (2) improving understanding of the physics and chemistry of stratosphere and upper troposphere (e.g., ozone).

Continental shelf, coastal estuarine processes. Research seeks to develop a comprehensive interdisciplinary program that will aim at modeling the dynamics of shelf and deep water circulation phenomena as well as ocean wave climate in the U.S. oceanic regions. Other areas include determination of the behavior and circulation patterns of nearshore and estuarine water masses; and analysis of the location and description of catastrophic phenomena active on the continental shelf such as slumps, slides, mass sediment transport, etc., through microbathymetric analysis and close grid surveys.

Fine structure of the geoid. Future research seeks to: Determine the nature and origin of fine structure features in the geoid (wave lengths of less than 100 kilometers); develop a unified approach to geodesy in the United States (unification of horizontal and vertical base data); determine the relationship between geodetic and gravimetric fluctuations over the continental shelf and continental areas of the United States; determine the rate of elevation change in tectonically active areas of the United States; and use and develop very long base interferometry (VLBI) techniques to determine polar motion rates over the United States.

The Global Weather Experiment (GARP/FGGE). The research activities under the global atmospheric research program (GARP) will continue. This includes plans and preparations for FGGE (the Global Weather Experiment), the operational phase of which is scheduled for 1978 and 1979. Research on the GARP Atlantic Tropical Experiment (GATE), the field phase of which was carried out in 1974, will also continue.

Climate. The effect of aerosols on climate will be studied, as will the human impact on climate. For the longer term (10 years), the research priorities in the climate area include climate diagnostic research.

Weather modification. Research initiated in the late 1960's to develop a sound scientific basis for weather modification will continue. This will include field experimentation on hurricanes and convective clouds.

Sea-air interaction. Surface meteorological and oceanic data to determine the effect of atmospheric forcing on the local mass and motion fields of the upper ocean will be analyzed. Initial analysis

will concentrate on the unique set of GATE surface and oceanic data.

Promising or vital areas of research, not now supported at an adequate level but involving basic research that warrants increased emphasis and support, are discussed below.

Carbon dioxide in the oceans and biosphere. This involves the measurement and analysis of carbon dioxide concentrations to understand the buffering of atmospheric carbon dioxide by the oceans and the biosphere.

Mesoscale atmospheric processes. Investigation of atmospheric motions on the mesoscale through comprehensive measurements from a mesoscale network and associated analysis and research is an important research area.

Role of oceans in climatic and short-term variation. A sea-air interaction investigation is needed to determine the role of the oceans in climatic variation, in which emphasis would be on understanding and predicting year-to-year fluctuations in climate rather than long-term trends. Initial interest is in the fluctuations in the Equatorial Pacific Ocean because of their association with U.S. climate. Basic research is also needed to develop methods for parameterizing the effect of the subsynoptic variations on the air-sea transfers of heat, water vapor, and momentum.

Ocean dynamics and coastal processes. A comprehensive ocean wave and ocean modeling program for the U.S. ocean waters should be developed. Involvement with the large-scale water tectonic project—MODE and POLYMODE and NORPAX—should be expanded. A comprehensive continental coast tidal program to look at the nature and the rate of change in elevation and position of the U.S. Continental Shelf region should be developed. The study of polar motion through the use of very long base interferometry techniques in conjunction with NASA appears promising. Bathymetric forms, their origins, and their association with catastrophic submarine events should be studied.

Climate diagnostics. Empirical analysis of climate data and preparation of specialized climate research data sets and sun-weather/climate research are two important research areas concerning climate diagnostics.

Stochastic processes in hydrologic forecasts. For the hydrology program basic research is needed to extend the state of the art in the theory of stochastic processes to represent more clearly space-time variations in factors affecting the uncertainty of hydrologic forecasts. This would involve uncertainty in the atmospheric general circulation models and in the input data to these models. It would involve the development of techniques suitable for describing the space-time differences between atmospheric forecasts and actual occurrences. Stochastic theory is needed to be able to combine in space and time uncertain information from remote sensing systems such as satellites, aircraft, and ground-based radar with other information now used as inputs to river forecast systems. Finally, basic research is needed in estimation theory and state space modeling for nonlinear, time-varying systems.

NATIONAL BUREAU OF STANDARDS

NBS Mission

The National Bureau of Standards (NBS) was established by Congress to provide the Nation—its citizens, private enterprises, and Government—with a national basis for physical measurement. In today's highly technological society, the Bureau continues to serve as the central reference laboratory for measurements and standards for the Nation. In addition, it has become a science and technology (S&T) resource for Government which can operate in a third-party manner and a technical arm of the Department of Commerce. In this latter capacity, it is broadly supportive of productivity and efficiency in industry and Government, technological innovation and competitiveness of business, and equity in consumer affairs.

All of these functions are dependent on the Bureau's being first and foremost a research institution, because the quality of NBS services stems from the breadth, vigor, and excellence of the scientific research base. The Bureau's research is carried out in laboratories located in Gaithersburg, Maryland, just outside Washington, D.C., and in Boulder, Colorado. The total full-time permanent staff is about 3,600, with about 1,500 professionals, most of whom are physical scientists.

NBS was founded in 1901 in response to the need for measurement and standards due to the burgeoning commerce and industrialization of the United States in the last part of the 19th century. As science and technology proliferated and became more sophisticated during the 20th century, the breadth and scope of the technical and scientific activities at NBS grew as well. Although the

basic legislative organic act of 1901 has been updated and amended from time to time, the original functions have not been altered; however, there has been a growing tendency in recent years for Congress and the executive branch to assign specific responsibilities to NBS in areas of urgent national concern. For example, in response to recent congressional acts, the Bureau has established a Fire Research Center, developed technology to determine the safety of consumer products, evaluated new nonnuclear inventions for energy conservation or production, and developed standards for reclamation of used oils. In response to executive directives, programs have been established to explore the impact of Government policy on technological innovation in the civilian sector and to develop and disseminate technical information of use to consumers.

In performing its mission, the Bureau has developed a staff with high scientific and technical credentials and has become a national resource with far-reaching impact. It has catalyzed the application of technology and scientific methods to societal problems, has been a technical arm to other Government agencies, and has been a spawning ground for new scientific or technological services within the Government.

The contributions the Bureau must make to fulfill its mission are credible only to the extent that they are based on the best scientific and technical judgment available. Thus, management and congressional oversight have recognized that the fundamental triad of standards, measurements, and data that are needed by U.S. scientists and engineers can only be addressed in the context of an institution steeped in the scientific disciplines, with a staff actively participating in forefront research in those disciplines. In addition, basic research enables it to respond to future demands for services in real time.

The "people dimension" in this matter is crucial. NBS staff members of the intellectual stature capable of carrying on basic research are essential for maintaining the vigor of the institution. NBS, like any vital scientific laboratory, must be permeated by an intellectual spirit of inquiry that only basic researchers of high caliber at the cutting edge of science can provide.

Definition of Basic Research

NBS therefore not only feels a commitment to provide services to those who do basic research but must itself be involved in this research in order to perform its mission. In this context, the National Science Foundation (NSF) definition of basic research as an activity unrelated to the goals of the organization is too severe for our use. For us, then, basic research is that generally goal-oriented forefront disciplinary research, which has long-term significance and which has intrinsic scientific value beyond the limits of the specific mission and goals of the organization. The general areas of such research will be viewed by management as supportive of the mission and by the individual researcher and his peers in its scientific context.

Much of the justification given above is equivalent to that for basic research in any high technology or scientific institution with long life expectancy. However, the unique NBS mission gives its research a special flavor, because the Bureau has the institutional responsibility for making available to the public the best values of the basic physical constants of nature. Although pursuit of accuracy and precision in physical measurements may not always be forefront conceptual science, such pursuits are often closely associated with forefront science for two reasons: (1) Improved accuracy and precision in experimental science are part and parcel of the process of improving the tools of science, and they improve the determination of the physical constants underlying that conceptual framework; and (2) absolute precision measurements often have direct impact on conceptual science. The history of science provides numerous examples: Argon was discovered by measuring the atomic mass of deoxygenated air accurately. The relationship of the velocity of light to static current and electrical measurements as predicted by Maxwell was confirmed by measurement; and vacuum polarization was confirmed through precise measurement of the fine structure constant in hydrogen.

Role of Basic Research

Because of the Bureau's deep involvement in science over the years, it has become a crossroads for science. This tradition is typified by the role NBS played till the 1950's as host for annual meetings of the American Physical Society in Washington. During this period, before the society outgrew NBS' physical plant, the technical sessions of the society were held on the premises of the old Bureau site on Van Ness Street. NBS still plays a crossroads role for science and technology through its national symposia, weekly colloquia, and workshops, thereby hosting some 14,000 scientists and engineers each year.

Basic research at NBS has come under a varie-

ty of pressures similar to those at most research establishments during the late 1960's and 1970's. It is easier to discuss the cause of these pressures than to quantify them or their effects. There has been a constantly increasing number of congressional acts and executive branch directives mandating that NBS provide short-term services. The demands of the other agencies for short-term technical assistance in performing their missions has grown markedly. The demand for paperwork in justification has grown. Because of the increased sophistication of technology and the severity of some of the aftereffects of technology, NBS services have become more complex technically and increasingly require interdisciplinary program management. All of these increased demands on the Bureau have occurred during a time when the personnel ceiling and constant dollars were essentially static. Deterioration of the environment for science as seen by the scientist was inevitable. Scientists have been redirected from basic research to short-term projects and/or program management tending to drive out long-term concerns. Although statistics do not tell the whole story, they are informative.

In 1975, the congressionally mandated Visiting Committee for NBS sponsored a major study of the "state of health of research at NBS," chaired by Professor R. Dicke of Princeton University, who is a member of the NBS Statutory Visiting Committee, and A. McCoubrey, Director the NBS Institute for Basic Standards. As part of this study, middle managers (Division Chiefs) were asked to estimate the amounts of long-term disciplinary research in their organizations in 1965 and 1975. (Long-term disciplinary research is synonymous with basic research as defined in this article.) In the predominantly science areas — Institutes for Basic Standards (IBS), and Materials (IMR) — this research decreased from about 35 percent of the total work in 1965 to about 17 percent in 1975, averaged over all the Divisions. In the applied areas — Institutes for Applied Technology (IAT), and Computer Sciences and Technology (ICST) — the corresponding reductions were 5 percent to 2 percent. The middle managers thought that the optimum levels for such research at NBS were about 25 percent and 30 percent in the science areas and 10 percent in the applied areas. These estimates by the middle managers are about as accurate an assessment of trends and the desired level of aggregated basic science at NBS as can be obtained.

At NBS and elsewhere in the Nation the climate surrounding the conduct of basic research has inevitably suffered in recent years from the external pressures on research. While the closer coupling of science to technology has been beneficial in many cases, the climate for long-term research has suffered. If this climate is to be improved, a more explicit recognition is needed throughout the Federal S&T governmental structure of the value of basic research to the institutional health and vigor of a mission-oriented laboratory. This climate could also be improved by a more explicit recognition of the fact that the vital core of a basic research program is its scientific merit and creativity. A better climate would probably exist if the evaluations of programs in the budgetary process considered the intrinsic scientific and technical merit of the research involved, and relevance was measured against the long-term mission of the laboratory as well as the short-term effectiveness.

A scientific group of high vitality and creativity is characterized by a free-flowing atmosphere of ideas and people. A greater flow of people into and out of NBS would improve the research climate. In addition to improving the quality of in-house research, this flow provides the staff with a window on developments in basic science. That is, this flow helps the NBS staff keep aware of new developments in science elsewhere which have the possibility of having future impact on the NBS mission. Both kinds of people movement are desirable—sabbatical-like leaves for the permanent staff, and expanded opportunities for selected scientists to visit NBS for extended periods. Indeed, the general level of people-exchange among the research organizations of the Nation is probably not at an optimum level for the most creative exchange of ideas. The NBS postdoctoral program addresses this issue and is highly valued. The matter of travel, which is a perennial issue in the Federal Government, also contributes to this flow of ideas by staff attendance at conferences, etc., and is crucial for the research staff.

Finally, there is the matter of equipment. NBS has been engaged since 1974 in a program of capital equipment modernization. While this program is in effect, a reasonable rate of modernization can be accomplished, and the most serious deficiencies will be ameliorated.

A more fundamental question regarding equipment which transcends NBS is the proper use of a wide-spectrum Federal research installation like NBS as a site for placing major facilities that are available to other scientists on a regional or even a national basis. NBS presently operates a number of facilities in this way (e.g., an excellent nuclear reactor, an electron accelerator (LINAC), a synchrotron light source, mechanical testing machine, etc.). However, this general principle has a deeper basis. In the sciences generally there is a pervasive increase in the cost of the tools for doing research, which escalates faster than the

support level itself. This trend means that more and more sharing of facilities will be necessary on a nationwide basis, and NBS is a natural place to share facilities, provided adequate support is available. Specific examples which might be candidates for such an approach are analytical chemistry, materials characterization, spectroscopy, buildings research, fire and combustion research, as well as others.

High capacity computer facilities are an especially interesting candidate for sharing between laboratories. With the strong trend running toward decentralized computer usage with the small dedicated computer, the possibility should be explored of regional cooperative systems for those investigations requiring a state of the art, high capacity computing facility. The Washington, D.C., area may now be ripe for such a development.

NBS has already recognized and attempted to respond to some of the trends and issues discussed above. For example, the "state of the health of research at NBS" carried out by Dicke and McCoubrey suggested increasing the people flow through the laboratory. In response NBS will double the postdoctoral program from about 40 postdoctorates to about 80 over a period of 6 to 8 years. The report also recommended setting up a committee composed of working-level scientists and engineers to advise the Director on matters of research opportunities and research climate. That committee has been in operation for about a year and has made a number of recommendations. Other internal ways and means for improving the climate and general health and vigor of basic research are being discussed and explored.

The intent of this paper is to show how NBS, by performing its primary mission of providing standards, measurement methods, and scientific and technical data, has become a broad-gauge scientific laboratory which has also served the Nation well in the front ranks of basic science.

Changes in the style and role of basic science throughout the United States during the past decade and the added requirements on NBS for short-term outputs have changed the environment for long-term research at NBS and placed pressures on the conduct of basic research. NBS has recognized its special need to preserve and cultivate capabilities in basic research and strives to keep the vitality of its basic research high.

The fundamental issue regarding basic research in the Government laboratories is the need to maintain a Federal policy that encourages basic research of high quality. A laboratory such as NBS must be encouraged to carry on a significant level of basic research in support of its mission, and to foster a cadre of staff who operate with distinction at the forefront of science in order to maintain the technical vigor and viability of the laboratory over the long term. A corollary to this policy is that the management process that governs this enterprise should recognize two criteria for the support of such research: (1) The research should be generically relevant to the long-term mission of the laboratory, and (2) the research should be judged on the basis of its intrinsic scientific value. The selection of basic research areas on the basis of short-range program goals is not feasible. Finally, the current level of effort of basic research at NBS should be increased, and in keeping with the increasing importance of S&T in the country, methods should be found for increasing the flow of people and ideas through the laboratory.

Beyond these observations, another important need is to establish procedures and methods within the scientific community by which greater sharing of major scientific equipment and facilities can occur. Facilities contained in major laboratories such as NBS should be made more available to outside users. NBS has both wares to offer (a nuclear reactor, unique analytical capabilities, mechanical testing facilities, etc.) and needs (e.g., access to high speed/high capacity computers, high energy synchrotron light sources, etc.). In order to achieve this goal, both funding procedures and institutional arrangements will have to be established.

Current and Future Research Emphasis

The purpose of this section is to review briefly the major lines of research at NBS and indicate some areas of special interest for the future. Because NBS research extends into nearly all the major disciplines of physical science, including mathematics and selected areas of engineering, this review must be limited to examples and highlights.

Before entering into the details of our discussion, however, four examples of work at NBS which figured in discoveries leading eventually to Nobel Prizes will be mentioned to illustrate the caliber and impact of basic research at NBS. These are the concentration of heavy hydrogen by Brickwedde in 1931; the scattering of neutrons in para and ortho hydrogen by Brickwedde, Hoge, and others, which showed that neutron-proton forces were spin dependent; assistance in the design and construction of the bubble chamber by Birmingham, Chelton, and Mann; and the experimental verification of the violation of parity conservation in weak nuclear forces by Ambler,

Haywood, Hoppes, Hudson, and Wu. In addition, work by Maxwell at NBS demonstrated the isotope effect in superconductivity simultaneously with workers at Rutgers, an experiment which laid the ultimate basis for the Bardeen, Cooper, Schrieffer (BCS) theory.

Physical Measurements

Measurement science as practiced at NBS is synonymous with the development and use of the tools and instruments of experimental science and technology for more precise and powerful measurements of the physical world. Although every experimentalist is therefore also a practitioner of measurement science, NBS has an institutional responsibility to foster it. Thus, as mentioned earlier, measurement science colors the entire research effort at NBS and receives continuing high priority. One indication of the marked progress in measurement science can be seen by comparing the best values of the physical constants listed of 1959 with those of 1975. In general, the precision has increased by factors of thousands.

As a specific example, the frequency spectrum standards system has been expanded in overlapping steps from 4×10^{10}Hz to about 10^{20}Hz (microwave frequencies to γ-rays). Not only has the level of precision been improved markedly, but the long-standing dichotomy between the optical and x-ray regimes has been removed.

Of all the other examples of areas where measurement science is pursued at NBS, we mention analytical chemistry. This area is also of interest because of the important national problems which are addressed. For example, pollution abatement, industrial quality control, and clinical chemistry are all analytical chemistry intensive. A major challenge for the future is in the development of sensitive, accurate techniques for the determination of organic compounds in diverse media. Here the ability to separate and characterize becomes paramount since the samples may have hundreds or even thousands of potentially interfering constituents.

In the future as in the past, measurement science will be the principal driving force for basic research at NBS and to a large extent will determine the style of NBS research. The needs in measurement science will be for more precise values of the basic physical constants, for more sophisticated chemical analysis, for more accurate characterization of materials, and for more accurate and economic techniques for making all sorts of physical measurements of temperature, sound, electromagnetic fields, etc. In pursuit of this challenge, NBS expects to continue to operate at the forefront of the physical science disciplines and integrate research in the disciplines to provide the measurement services needed in areas of major national concern. Examples are nuclear safeguards, energy, government regulation requiring a technical basis, health, safety, and technology underlying better consumer information.

Atoms and Molecules

This category of research encompasses new and promising research opportunities covering much of physics and chemistry.In it, NBS conducts experiments and develops theory for describing the basic properties, such as configurations, interactions, and transitions of atomic, molecular, and ionic species. The data and theories developed form the basis for modeling and understanding the equilibrium and nonequilibrium states of such important systems as fusion plasmas, lasers, and the earth's ozone layer. They also form the basis for prediction and control of chemical reaction rates in all their multifarious applications.

NBS is presently analyzing the very hot gases of interest to the national thermonuclear program. An extensive series of measurements is being made of radiation spectra, energy levels, transition probabilities, and electron impact excitation. Of particular scientific interest is the first definitive beam measurement of the cross section for electron impact of a multiply-charged ion (C^{+3}).

By pioneering in the use of synchrotron radiation and the development of monoenergetic electron sources, NBS played a leading role over the past decade in discovering and understanding atomic and molecular resonances due to doubly excited states. A beam of electrons derived from laser-induced photo-ionization of metastable barium was used to resolve doubly excited states to about 1.5 meV, or more than 10 times better than previous techniques. This new precision will allow much more thorough tests of the theory, much of which was developed at NBS.

A new spectroscopy has been developed at NBS and is becoming widely adopted elsewhere, wherein molecular continuum radiation is quantitatively measured and analyzed to determine molecular potentials of colliding gases, when one of the collision partners is excited. The increasing application of lasers to atomic and molecular spectroscopy has brought with it the additional complexities of nonlinear or multiphoton processes. The physics of such processes is being explored theoretically and through experimental studies of multiphoton ionization in very diffuse alkali vapor as well as in dense alkali plasmas.

Further laser research at NBS has led to their use for selectively exciting molecular transitions which allow very sensitive analytical detection of

molecular species and permit the study of state-to-state selective chemistry. Thus, detailed dynamics of state-to-state bimolecular collision processes can be determined. These experimental studies are complemented by theoretical work on molecular excited states. Experimental investigations have indicated the inadequacy of the conventional rate theory model (based on the activated complex) for predicting vibrational enhancement of chemical rate processes in certain systems. This activated complex model has been a central fixture in chemical kinetics theory for many years, so these findings are of considerable fundamental significance. Another new area of laser chemistry is that of laser-induced photodissociation, the basis for isotopic selective photofragmentation, which is of intense interest to the Energy Research and Development Administration (ERDA) as a promising new technique for nuclear fuel enrichment. NBS has played a major role in the basic research behind ERDA's efforts.

As to the future, the use of new tools, and especially of lasers, for studying excited atomic and molecular states, and state-to-state transitions between them is recognized nationally as a new and scientifically exciting approach to developing new concepts underlying chemical reactions, broadly defined, and to finding powerful new insights into all phenomena where atomic and molecular processes are involved. The full exploitation of the potential of atomic and molecular science will require extensive collaboration by chemists and physicists, and theory as well as experiment. NBS is in an excellent position to play a major role in the future unfolding of this significant field.

Nuclear Science

NBS has maintained research programs in nuclear science from near its beginning, derived partly from early involvement in radiation standards and later in nuclear measurements. An example of recent work at NBS is the precision measurement of electron scattering at the NBS linear accelerator (LINAC), in which NBS workers have collaborated with groups from numerous universities in this country and abroad and from other agencies of Government. Accurate hexadecapole measurements of deformed heavy nuclei have provided unique information on the radial charge distribution.

A second example is the investigation of the normal modes of the nucleus and the giant resonance of the nuclear electric dipole. As early as 1965 theoreticians conjectured that the giant resonance should couple into the quadrupole vibrations of the nuclear surface. At NBS, calculations were made of the expected cross sections, and the predicted effects were subsequently measured with plane polarized monochromatic γ-rays. Within the limited precision available, photons were observed to be scattered along the incident polarization vector, due to the coupling to the spherical vibrations, while no scattering in this direction was measured from the rigid spherical nucleus of ^{209}Bi, as expected, in a beautiful confirmation of the theory. Other theoretical work has also dealt with many aspects of high energy electromagnetic reactions ranging from radiation transport to few nucleon dynamics and elementary particle interactions.

In the near future NBS research on nuclear structure will make two major thrusts. In the first, improved experimental resolution of electron scattering will be combined with improved counting rates to allow the study of the more closely spaced and weaker nuclear excited states. The second thrust will use a monoenergetic photon beam obtained from inflight annihilation of LINAC positrons to study nuclei by means of elastic and inelastic photon scattering.

In the long term, further advances in understanding nuclear structure by means of electromagnetic probes will demand detection of nuclear decay products in coincidence experiments. These experiments will require accelerators with a much higher duty cycle than the present NBS LINAC.

Thermal Studies of Matter

NBS has for many years been in the forefront of the study of the thermal properties of matter. An international conference on critical phenomena, held at NBS in 1965, marked the beginning of a mature understanding of that field. At this conference, the apparent universality of critical point behavior was first clearly demonstrated. That is, the behavior of a material near its critical point was found to be independent of details such as the atomic force laws, at least in a large variety of cases. Research at NBS has concentrated on clarifying and extending the universality concept by making high precision measurements on fluids and fluid mixtures near their critical points.

Theoretical studies of liquid structure and spatially disordered matter have led to a first-principles theory of first-order phase transitions (e.g., melting-freezing), and has made possible for the first time an investigation of the properties of thermodynamically metastable states without invoking arbitrary and unjustified assumptions. Computer simulation of shock waves in lattices is being used to study the response of solids to strong perturbations from thermal equilibrium.

A principal challenge of much of this work on the thermal properties of matter, which will continue to be addressed in the future, is dealing with systems far from equilibrium. In nearly all analyses of kinetic phenomena, one now assumes that

the system is very close to thermal equilibrium and that local thermodynamic variables can be defined and measured. However, in many important situations, the system is far from equilibrium and the standard techniques and concepts do not apply. Theory at present has little to say about how to conceptualize this situation and consequently the meaningful measurements or physical parameters that characterize the system are not known. Theoreticians and experimentalists will address this difficult and fundamental question in the future by studying metastable systems, systems containing very large gradients of properties, and systems undergoing rapid dynamic changes.

Surfaces

NBS has made a major investment in surface science, with theoretical and experimental work in surface physics, surface chemistry, and metallurgical corrosion. From all indications, this field is on the threshold of many illuminating insights into important areas of application such as catalysis, corrosion, small particles, wear, and electronic devices.

An example of recent progress at NBS is the discovery that ions liberated from absorbed monolayers by electron-stimulated desorption have sharply peaked angular distributions which have the same symmetry as the single crystal substrates. The directions of ion desorption are related to the directions of bonds at surfaces, and the measurements provide a significant new potential for determining surface structure.

Theoretical work has addressed the electronic structure of chemisorbed atoms and in particular the energy dependence of field emission and photoemission of electrons from surfaces with adsorbed layers. Recent work has predicted directional effects in photoemission from which chemisorption orbitals and bonding geometries can be inferred. Specifically, the angular dependence of photoemitted electrons from "adatoms" bonded to a substrate has been calculated on the basis of further detailed calculations of the electron charge densities in the adatom. As a whole, the work by NBS workers and others on directional effects in surface measurement techniques has added a new dimension to the ability to observe, understand, and control basic surface phenomena on an atomic level.

NBS is also known widely for its corrosion research. For example, NBS corrosion research has been responsible for much of the development of ellipsometry into a quantitative tool for studying surface corrosion buildup. Significant contributions were also made to the application of field emission microscopy to gas-metal surface interactions, surface structure, and surface diffusion.

Surface science together with its applied fields of catalysis and corrosion is rapidly becoming one of the most significant scientific endeavors, not only because of important applications, but because of the promise of marked advance in science and technology as a result of the powerful research tools and scientific momentum being developed. NBS plans to play a significant role in the Nation's surface studies in the future through research in the relevant physics, chemistry, corrosion, and catalysis. In particular, NBS is challenged by technology's need to characterize the geometric and electronic properties of catalytic sites and by the need to measure the effects of catalytic poisons at the atomic level.

Experimentalists, in collaboration with the theoreticians, will continue to refine and advance the growing array of improved analytical techniques and contribute new insights and measures of electron-solid and gas-solid interactions and better descriptions of the electronic structure of surfaces.

Materials Science

Progress in materials science remains dependent on interdisciplinary scientific investigation and is a crucial nexus of application for many areas of national concern such as energy, health, safety, etc. NBS does substantial research in polymers, metallurgy, ceramics, glass, and semiconductors, and operates one of the Nation's most active research nuclear reactors for the benefit of outside users as well as for NBS.

At NBS, key contributions have been made to the characterization of polymers, and especially to the description of polymer crystallization by the chain folding process. Shortly after the idea of chain folding was proposed, a series of papers were issued at NBS that explained the important experimental findings and that established a theoretical basis for the kinetics of chain folding in terms of fluctuation theory. NBS pioneered in establishing the properties of III/V semiconductor oxides and was one of two groups that first found superconductivity in semiconducting materials. Mechanical properties and failure mechanisms in all types of materials are long-term activities at NBS. For example, NBS pioneered in measuring the static fatigue of glass and has shown how slow crack growth and acoustic emission can be used to provide reliability control in brittle materials.

The fundamental principle in materials science is to correlate the macroscopic properties of materials with the electronic, atomic, and microscopic structure. Future challenges in materials thus lie primarily in making this correlation more quantitative and inclusive. However, because this cor-

relation involves such a breadth of traditional branches of science, research in this field lacks the sharp focus of fields such as surface science. Therefore, our discussion of it will encompass several thrusts.

NBS is a leader in the study of the basic atomic structure itself through work on x-ray and neutron scattering, phase transformations, crystal growth, and electron microscopy. A recent National Academy of Sciences study of the scientific opportunities in neutron scattering research has highlighted the high potential of this field. Possessing one of the foremost neutron scattering groups in the country, NBS is in an excellent position to exploit these opportunities. Recent advances in complex and subtle ordering phenomena in multicomponent materials point to increasing scientific promise for this field as well, and NBS expects to continue to contribute in a major way.

An area of high priority and of special relevance to the Nation's energy programs is research on the performance of materials in extreme environments. NBS has a history of contributions and expertise in diffusion, crystal growth, electrical properties, structure transformations, mechanical properties, and corrosive processes, and in characterizing novel materials, all of which bear on the performance of materials in extreme environments.

The science underlying nondestructive evaluation and failure mechanisms is a timely concern of NBS. Responding to the growth in the national importance of nondestructive evaluation (NDE) to public safety, health care, and commercial productivity, and to promising advances in theory and experiment, NBS has established and will continue to support an interdisciplinary research program in NDE.

Special notice should be taken of the interfaces between materials science and biology. Increasingly, the biological research community is using synchrotron light souces, neutron sources, nuclear magnetic resonance machines, and other tools of the material scientists. NBS fosters and participates in a national collaboration which is beginning between the material and biological scientists who share measurement problems. This collaboration will bring considerable benefit to both fields.

Mathematics

In the course of developing mathematical techniques to meet the needs of NBS scientists and the wider technical community, the Bureau's mathematicians have contributed significantly to numerical analysis, statistics, and operations research. When computers became commonplace, NBS numerical analysts turned to the study of methods for validating and maintaining accurate algorithms. Work in the mathematical methods of operations research has focused on optimization techniques, problems of network routing and design, and models and methods for optimal facility location. Interest is increasing in the theoretical and conceptual problems that surround the comparative testing of competing "optimization" algorithms, the evaluation of large-scale mathematical models, and the improvement of the model-development process.

Methods of mathematical statistics have been developed to foster the efficient use of experimenter's time and materials in the planning and analysis of precision measurement experiments. The results of combinatorial analysis have provided partially balanced incomplete block designs, fractional factorial designs, and other experiment plans. The growing challenge is to couple experiment design with sampling theory to provide a sound basis for error analysis of physical measurements arising in pollution abatement and the application of other technological standards.

Engineering

NBS recognizes the importance of long-term disciplinary research in the traditional engineering fields and supports relevant advanced research just as in the case of physics and chemistry. The principal areas of research are: fire phenomena, building technology, and electronic technology. In all three areas, strong interconnections are being developed to the research previously discussed in mathematics, materials science, physics, and chemistry.

Fire research. NBS operates the Federal Government's fire research center and performs research on the prevention and control of fires, conducting both intramural and external contract research.

NBS is applying laser diagnostic techniques to fire research. Chemical species in the flame are detected and the temperature of the flame is measured simultaneously. Other research includes the analysis of the basic reaction kinetics in flames with and without additions of retardants and of the properties of smoke particles and of pyrolysis. Mathematical models are developed for fires.

Fire research is a particular challenge to scientists, requiring the pooling of interdisciplinary expertise from chemistry, physics, materials, and mathematics, a process that is in its early stages of development at NBS. Heretofore, fire research has been considered too complex to attract much attention from the top researchers in physics and chemistry. Fire research is closely allied to combustion research, a field now receiving intense national attention, and will benefit from and contribute to that effort. In particular, advances dis-

cussed earlier under "Atoms and Molecules" (especially laser chemistry) should make major contributions to fire research. Mathematical modeling of the hydrodynamical nature of fires, including chemical reaction phenomena, will receive growing attention at NBS.

Building research. Building science at NBS encompasses an unusually wide spectrum of science, including behavioral psychology, bioacoustics, analytical chemistry, computer science, heat transfer and thermodynamics, and solid mechanics and fluid flow. Significant contributions have been made in recent years in the development of wind data around a building for structural and air leakage analysis, properties of unreinforced masonry walls, progressive collapse, ground heat transfer for underground systems, mathematical modeling of building thermal systems and energy performance, multiphase and multicomponent fluid flow in the plumbing systems, and the physical chemistry of paint and asphalt.

The central mission for the future of building science at NBS is to develop performance criteria for building design, either as a whole or in its various aspects. Future challenges in building science are the development of technical data useful in the design and evaluation of a building in terms of combined and optimum requirements for habitability, durability, serviceability, energy conservation, life-cycle cost, and structural safety, as well as architectural acceptability.

Electronic technology. NBS addresses the measurement and reliability questions that underlie the manufacture and use of all types of solid-state electronic devices, and its research encompasses such diverse disciplines as solid-state physics, physical chemistry, electrical engineering, analytical chemistry, optics, and sensitometry.

Research in this area at NBS is designed to characterize the effects of dopant and unwanted impurities in semiconductor materials and has resulted in a technique for the detection of sodium atoms in an atmosphere at hitherto unattainable low levels (10^4 atoms/cm^3). NBS scientists also have reinvestigated and corrected old and inaccurate conversion procedures for obtaining the impurity concentrations in silicon from measurements of its resistivity. This conversion is basic to semiconductor device design, performance, and material specification. In other work to provide methods for measuring line widths in photomasks used in the microcircuit fabrication process, the basic theory of optical microscopy was improved so that one-half micrometer line measurements can now be made to an accuracy satisfactory for industrial use.

The measurement techniques required now as microcircuit device technology breaks into the submicrometer-size regime exceed the present state of the art in important areas. These include basic electrical measurements on finished devices (voltage, current, and capacitance), advanced analytical techniques for trace impurities at the part-per-billion level, and dimensional metrology at the submicrometer level. In addition, new methods for testing increasingly complex integrated circuits such as microprocessors both functionally and parametrically need to be developed. This area thus becomes one of major application for measurement science at NBS for the future.

Below are some areas of high scientific potential and interest for future support where the NBS mission is directly involved and where NBS possesses the necessary technical and scientific talent.

- Measurement science is part and parcel of the substance of each of the areas mentioned below. One area, organic analysis, deserves special attention. Improved instrumental techniques including gas chromatography, mass spectroscopy, nuclear magnetic resonance (NMR), and Raman spectroscopy are being applied vigorously in the area of identifying and measuring organic species at concentrations down to the part-per-billion level. The formidable scientific challenges are paralleled by urgent needs for this capability in environmental water quality and in biomedical research. The need for standards and new techniques for both applications has stimulated a significant research effort.
- Atomic and molecular science is in ferment, with NBS occupying a significant position at the forefront. Scientific results of great power involving such fundamental concepts as mechanisms underlying chemical reaction rates are being produced with implications for pollution measurements, ozone layer dynamics, very high temperature plasmas, new lasers, and measurement science of value to industrial chemistry.
- The science of surfaces is gaining scientific momentum due to the development of powerful analytical tools, e.g., recent results that give inferences about bond direction of adsorbed atoms. Surface science has a high potential for ultimately developing predictive power for catalysis and corrosion applications, and will be important for applications to the properties of small particles where the surface-to-volume ratio is high. NBS has a particularly effective research effort in surface science.
- A major challenge of materials science is to improve our understanding of the relation of

materials atomic and microstructure to materials properties. New insights in phase relations and kinetics, plus increasingly sophisticated tools such as neutron scattering for the study of structure, promise a new plateau of achievement in predicting this relationship. Revolutionary possibilities exist for the application of modern physical ideas to mechanical failure and ultimately to NDE because of the still primitive level of understanding of the basic physical bases for deformation and fracture and of the empiricism characteristic of NDE applications. High temperature and extreme environments, especially in their applications to energy problems, represent a new frontier for materials applications with a new configuration of measurement problems.

- Fire research is a high potential area for the application of basic chemistry, physics, and mathematics in interdisciplinary teams to studies of the basic phenomena underlying combustion and fires.
- Nuclear science looks to ultimate resolution of the very closely spaced levels in the excited nucleus by a succession of improved experimental techniques. In the long term, this type of research will require detection of nuclear events by coincidence measurements, which will require an accelerator with a longer duty cycle than the present LINAC.
- Several branches of mathematics bear directly on the success of future programs at NBS. Among these are analysis, statistics, and computer science with work on optimization algorithms, large-scale mathematical models, evaluation and methodology, and application of sampling theory to measurement science and standards.
- The problems of nonequilibrium systems is one of the classic areas of science where a fully satisfying conceptual basis is still lacking. Collaborative interactions with atomic and molecular science and phase transformations in materials give this area special interest.
- In serving as the central focus for buildings research in the U.S., NBS future research will concentrate on all aspects of the technical data that underlie the building design and use cycle.
- The next generation of electronic technology will break through the size barrier at the micrometer level which is imposed by fabrication technology based on visible light. The measurement requirements of the submicrometer regime are severe. Measurement requirements will become more severe as the fabrication technology advances toward x-rays, or high energy electrons.

Organization and Management of Research Activities

From the management viewpoint, there is no special category of policies or procedures that relate specifically to basic research, as distinct from any other form of research.

NBS uses four principal means of evaluating its research programs:

1. Internal management reviews are conducted at each level in the organization. These culminate in an extensive series of program presentations made by the program managers to the Director and the Executive Board. These reviews are structured so as to air the performance of each program systematically before all levels of NBS management to allow fresh insight and criticism with respect to the performance and relevance of the programs. The endpoint of this annual process is the establishment of priorities.

2. To obtain an external perspective, NBS contracts with the National Academy of Sciences to provide an independent review and evaluation of NBS programs. The 29 panels that evaluate the NBS are made up to a total of 236 top-ranking scientists and engineers drawn by the Academy from industry (50 percent), universities (40 percent), and Government (10 percent). An Executive Committee of panel leaders considers issues common to more than one part of the Bureau.

3. The entire Bureau is surveyed and evaluated by the National Bureau of Standards Statutory Visiting Committee. This standing committee is appointed by the Secretary of Commerce and reports to him annually upon the efficiency of the Bureau's scientific work and the condition of its equipment.

4. To carry out the comprehensive and extensive analysis of issues in selected program areas, the NBS undertakes special evaluations. These evaluations are done by qualified contractor personnel, competitively selected, who operate under the direct program management of the NBS staff.

NBS makes use of a variety of mechanisms to promote a proper climate for research. In 1955, NBS pioneered a governmental postdoctoral research associateship program modeled after the practice established in American universities. This program is now administered for many Government laboratories through the auspices of the National Research Council and has become very successful. During the early post-war period, NBS invented a new kind of collaborative effort

with universities when it set up jointly with the University of Colorado in Boulder a laboratory for the study of upper atmosphere science, Joint Institute for Laboratory Astrophysics (JILA), with funding shared with the Defense Advanced Research Projects Agency (now with NSF). JILA still functions as an outstanding example of Government participation with a university in basic research and has become a world leader in atomic and molecular science. NBS doors are also open to scientists who want to collaborate with its staff on a temporary basis. Many of these are local faculty members who make use of special facilities at NBS such as the nuclear reactor, while others stay for longer sabbatical periods. NBS has an industrial research associate program which attracts scientists and engineers to work with NBS on problems of mutual interest.

MARITIME ADMINISTRATION

The Maritime Administration (MarAd) promotes the development, operation, and maintenance of an efficient American-flag merchant marine capable of meeting the commercial and military shipping requirements of the United States. To carry out this mission, MarAd assists the maritime industry by promoting shipper patronage of U.S.-flag vessels, developing advanced transportation systems and shipboard equipment, evaluating ship design, training merchant marine officers, and providing financial support to American shipbuilders and operators to narrow the cost advantages enjoyed by their foreign competitors.

In the conduct of its mission over the past five years, MarAd, in cooperation with the maritime industry, has carried out a broad research and development program directed toward improving the productivity and competitive posture of the U.S. merchant marine through technologically based innovations. The general program is directed along two parallel paths which correspond to the structure of the maritime industry itself. There are major programs in advanced ship operations and in advanced ship development. Under advanced ship development, elements address the technologies of shipbuilding, ship machinery, and nuclear merchant ships. Under advanced ship operations, development programs are carried out in ship and cargo operations generally, ship control technology, and navigation and communication. These programs are designed to speed the development of new processes and methods to improve productivity in the operation of American flag ships and in American shipyards. They are each characterized by extensive participation and cost-sharing by the ship operators and shipbuilders, who also share in the planning and implementation of the programs. The cost of equipment development is shared by the commercial equipment manufacturers.

Within this total program, a portion of the effort is devoted to long-term research of a disciplinary nature designed to provide the concepts and capabilities upon which future development programs can build. Such research corresponds to the basic research category for this document as a whole.

In particular, the basic research addresses the classical naval architecture technologies of structures, hydrodynamics, and propulsors. In the propulsor area, emphasis is on advanced propeller design and materials to achieve improved efficiency. In the structures area, investigations are conducted to determine the effects of sea loads and vibrations on ship structures. Analyses in this area are conducted in cooperation with other agencies and the National Academy of Sciences. Hydrodynamics projects are aimed at improving the efficiency of moving vehicles through the sea, with emphasis on powering technology, speed, and maneuverability. For example, an extensive series of model tests has been conducted on new hull forms and their maneuvering limitations. In-house efforts in exploratory research involve human factors studies, ship automation and communications project support, energy/environmental research support, and technology transfer. Areas of special interest have been studies of wave heights and their effect on ship bending, hydrodynamics studies of new ship forms, and studies of the effect of propeller shape on the transmission of vibration to the ship. The latter work has led to the development of a new type of propeller, with extended trailing edge of the blade tips, which induces a much lower vibration level in the ship. This new design is also characterized by increased efficiency and reduced maintenance.

An important tool developed for the in-house work on maritime research is the Computer-Aided Operations Research Facility (CAORF). At this unique simulator, built around a typical wheelhouse and control center that uses computer-generated images of the changing scene projected on a wide screen, simulated ships of all types can be maneuvered through any harbor configuration or environment and traffic situation in real time. Many of the tests at CAORF will thus study the

complex problems associated with passage through dangerous and restricted waters, and evaluate the relationships between the watch officer, the ship dynamics, the wheelhouse and equipment, and the sea environment.

OFFICE OF TELECOMMUNICATIONS

The research and engineering arm of the Office of Telecommunications is known as the Institute for Telecommunication Sciences (ITS) and is located in Boulder, Colorado. The role of the Office of Telecommunications is to provide specialized research and analysis essential for increasing successful applications of telecommunications technology. In turn, the goals of the ITS are to:

- Increase the availability of usable spectrum by engineering methods.
- Increase the likelihood of satisfactory telecommunication system performance, as affected by natural, engineering, and economic factors.

ITS's contributions are made through three broad programs: (1) Efficient use of the spectrum, (2) engineering and evaluation of systems, and (3) electromagnetic wave transmission research and services.

These three programs are highly dependent upon one another. For example, transmission phenomena play an important role in determining whether radio systems will work in the field, as do questions of mutual interference between systems or subsystems. Variability of transmission loss through the atmosphere determines the physical separation between systems sharing the same frequency and thus affects the efficiency of spectrum use. Engineering of systems to obtain the required performance demands adequate knowledge of transmission loss and distortion, as well as the effects of interference.

Basic research in ITS represents a small portion of the total effort and is that long-term disciplinary research that underpins the engineering effort. It is found primarily within the wave transmission area. Most of ITS's work is in applied research.

In electromagnetic wave transmission research, the basic research effort is aimed at improving the successful deployment of radio systems designed to operate near the state of the art, insofar as propagation is concerned. Deleterious propagation effects form a basic limitation to the performance of radio systems. Attenuation, scattering, ducting, and refraction affect both wanted and unwanted signals. Scattering the multipath may limit the available band width.

Recent work of a long-term character of particular interest includes:

- Studies of the strength and width of the O_2 microwave spectra in relation to the attenuation of microwave signals.
- Studies of the effects of rain on terrestrial and satellite microwave paths, and development of predictive techniques.
- Development of improved models for predicting multihop high frequency.

DEPARTMENT OF DEFENSE

OVERVIEW—OFFICE OF THE UNDER SECRETARY OF DEFENSE FOR RESEARCH AND ENGINEERING

Submitted by Dr. George Gamota, Staff Specialist for Research, Office of the Director, Electronics and Physical Sciences

DEPARTMENT OF THE ARMY

Prepared by Dr. Ivan R. Hershner Jr., Assistant Director for Research, Directorate of Army Research

DEPARTMENT OF THE NAVY

Submitted by Dr. Robert J. Lundegard, Technical Director (Acting), Office of Naval Research

DEPARTMENT OF THE AIR FORCE

Submitted by Dr. Kenneth L. Jordan, Jr., Principal Deputy Assistant Secretary for Research and Development, Air Force

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

Submitted by Lt. Col. William A. Whitaker, Special Military Assistant to the Director of Defense Advanced Research Projects Agency

THE DEPARTMENT OF DEFENSE OVERVIEW

Science and technology in this country have grown substantially during the past 30 years and can be correlated with the support of basic research by the Federal Government. The military departments recognized early the value of basic research and developed methods for the support of researchers, which during and after World War II played a major part in the Federal research effort in science and engineering.

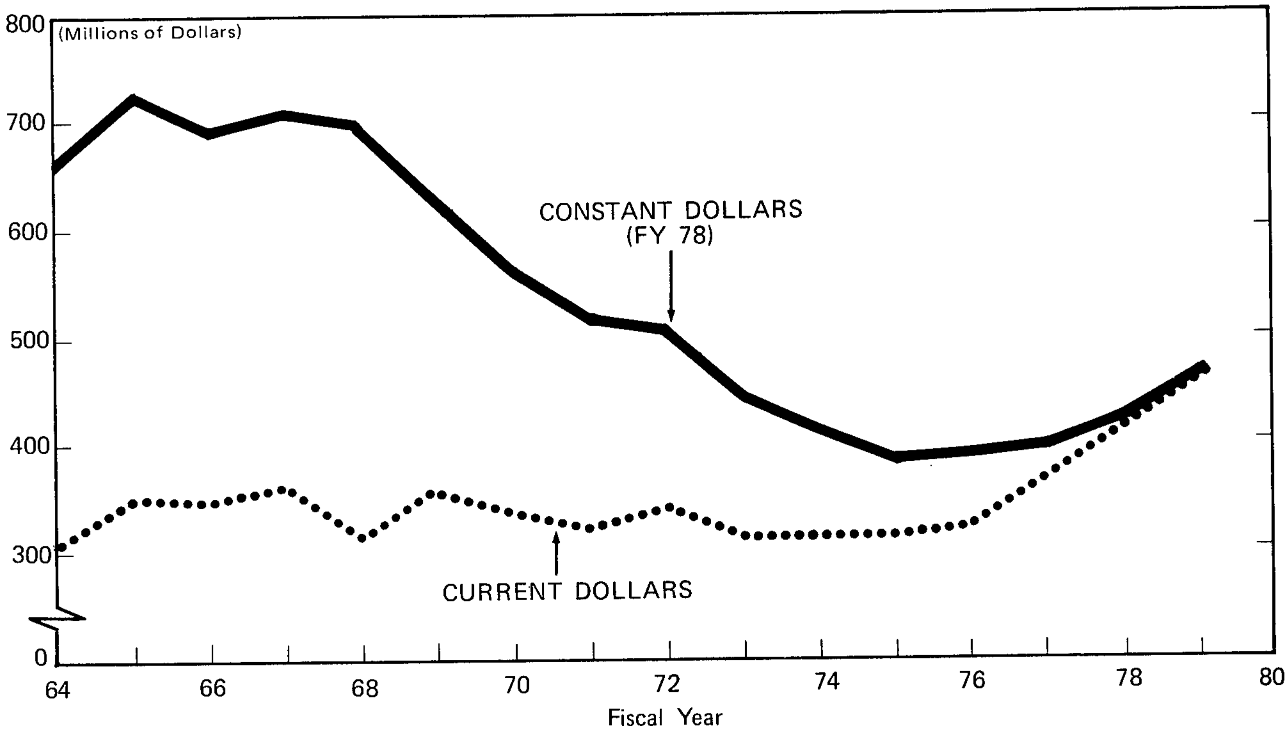
During the sixties, the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF) began to support basic research, following to a large degree the methods and patterns developed earlier by the military departments. Because of this new support, the Department of Defense's (DOD's) share of federally supported research dropped from over 60 percent to slightly over 20 percent in this period even though the actual dollar amount was increasing. In the late sixties and early seventies most of the previous patterns of growth in the support for basic research became stabilized and levels of support were even decreased if one takes into account inflation factors. (See Figure 1.)

Present Program

The present DOD research program provides a long-term foundation upon which to develop options for the solution of national security problems. It includes research in such fields as physics, chemistry, mathematics and engineering, and those aspects of the environmental, biological, medical, and social sciences that are unique to the military. About 40 percent of the research program is performed in the DOD laboratories, 40 percent in universities and colleges, and most of the remainder in industry. Table 1 shows the distribution of research funding for all three performers.

Five major organizations in DOD have major responsibilities for the research program: the Army, Navy, and Air Force, the Defense Advanced Research Projects Agency (DARPA), and the Office of the Under Secretary of Defense for Research and Engineering (USDRE). USDRE (formerly the Director of Defense Research and Engineering) has the overall responsibility to set funding levels and provide policy and guidance for the DOD research and development programs.

Figure 1. Department of Defense research program funding trends



Source: DOD

Table 1. Allocation of research funding for fiscal years 1976, 1977, and 1978 (in millions of dollars).

	FY 76	FY 77	FY 78
Army			
In-house	51	61	60
Universities	18	29	34
Other contracts	10	8	8
Total	79	98	102
Navy			
In-house	58	73	78
Universities	50	62	75
Other contracts	21	20	20
Total	129	155	173
Air Force			
In-house	48	21	21
Universities	24	33	37
Other contracts	12	31	37
Total	84	85	95
DARPA			
Universities	14	17	20
Other contracts	18	18	22
Total	32	35	42

Source: DOD

Each military department has an office of research which manages most of the contract research programs. The history, tradition, and organization of each department, as well as DARPA, will be treated separately in the following chapters.

Recent Research Initiatives

Here briefly are listed recent initiatives that are common to the programs of the military departments:

- Commitment to real growth of DOD research funding
- Increased emphasis on university research.

Regarding the first initiative, the Department has initiated actions to increase research, and, since FY 1976, a turnaround in the funding has been achieved (Figure 1).

The second initiative strengthens DOD-university ties in areas of potential interest to the long-term needs of the national defense. Emphasis will be placed on the quality of the basic research and on innovation. A DOD committee will be established to help guide the Department's university research programs.

The Future

The Department intends to continue its emphasis on a strong and healthy research program. The program will continue to be carried out by in-

house laboratories, universities, and industry. Each offers unique strengths and capabilities that must be used to provide technical options for long-term national security needs. The objective of the Department is not only to focus on military needs but also to provide a program that fully complements the total national research program. It is through the combined efforts of the research elements of the country that a viable and optimum research program can be maintained for the achievement of defense objectives.

DEPARTMENT OF THE ARMY

The Army's Mission

The basic mission of the United States Army is to foster stability, peace, and security, and to provide for the defense of the United States in conjunction with the other armed forces. The role of the Army is drawn from many interrelated sources—legal, philosophical, and historical. As an expression of the will and intent of the Congress, the Army's legal role—as expressed in title 10, United States Code, section 3062—is the principal basis of Army philosophy and doctrine. Under this statute:

> It is the intent of Congress to provide an Army that is capable, in conjunction with the other armed forces, of preserving the peace and security . . . of the United States; . . . supporting the national policies . . . implementing the national objectives; . . . and overcoming any nations responsible for aggressive acts that imperil the peace and security of the United States.
>
> . . . (the Army), shall be organized, trained, and equipped primarily for prompt and sustained combat incident to operations on land . . . (and) . . . is responsible for the preparation of land forces necessary for the effective prosecution of war except as otherwise assigned and, in accordance with integrated . . . mobilization plans, for the expansion of the peacetime components of the Army to meet the needs of war.

The law establishes a fundamental relationship between the role, philosophy, and doctrine of the Army and the broad considerations of the United States national security, policies, and objectives. The importance of this relationship is further accentuated by the present unsettled world situation. So considered, the Army's role is to train, equip, and organize its forces to provide the deterrence and assurance required to further United States national security interests in the world.

The Army's basic role within the American defense establishment is unchanging, but the real world in which that role must be played is shifting dramatically. As a result, areas of actual and potential turbulence are increasing significantly. Within this environment of change, it is the mission of the Army to carry out the landpower tasks of the United States so that turbulence is reduced, stability preserved, and peace promulgated. These are the broad objectives beyond any war, and their achievement requires the Army to be able to defeat enemy forces in land combat and to establish control over land and people. This is the basic rationale for maintaining the Army, in peace as well as in war.

No one can predict with certainty how the United States may be called upon to use its military power. Military forces must be prepared to support the national strategy in the face of any aspect of the threat. They should first of all be able to deter conflict; then to control war if one erupts; and finally, to conclude hostilities. This imposes an almost unlimited range of missions on the Army. It must be ready for, at least, the most important of them. This fundamental outlook is the galvanizing force behind the Army's posture. It means that the Army must stand ready to do anything modern military operations demand of American landpower, both today and in the future.

Definition of Basic Research

In furtherance of its mission, the Army supports an extensive research program including basic research. Although the Army does not specifically define "basic research," the operating definition for "research" is:

> .scientific study and experimentation directed toward: increasing knowledge and understanding in those fields of the physical, engineering, environmental and life sciences related to long-term national security needs; providing fundamental knowledge required for the solu-

tion of military problems; and forming a part of the base for (a) subsequent exploratory and advanced developments in Defense-related technologies and (b) new or improved military functional capabilities in areas such as communications, detection, tracking, surveillance, propulsion, mobility, guidance and control, navigation, energy conversion, materials and structures, and personnel support.

Role of Basic Research

The Army's policy concerning support of research is to:

- Maintain a strong and progressive research base by conducting a broad and continuing research program, including an adequate in-house capability, to provide fundamental knowledge with emphasis on those areas of special promise to the Army.
- Encourage and ensure investigation of new ideas and concepts that may contribute to the Army mission and/or reduce the cost of maintaining and operating Army systems and equipment.
- Encourage multiservice support of those facets of research that will affect the development programs of more than one military service.
- Support and conduct research in the fields of training and education for the broad purpose of reducing training time and costs and increasing training effectiveness.
- Maintain effective contact between the Department of the Army and scientists of the United States and, when appropriate, other nations of the free world.

Examples of Basic Research

During the past 10 years there have been many significant research projects (intramural and extramural) that have been supported or accomplished by the Army. Twelve of these projects, which show the breadth of the Army research spectrum, are listed below.

Trace Chemistry of Tropical Atmospheres

Dr. J. P. Lodge, Jr., and his team from the National Center for Atmospheric Research developed or adopted a series of tests for precise measurement of trace gases at remote tropical field sites. Using these tests, they conducted extensive studies in the American tropics to determine the temporal and spacial atmospheric trace substance concentrations in a variety of tropical environments, shoreline vs. inland, open vs. forest, below vs. above the forest canopy, ground vs. aloft, and dry vs. wet season, for which information had been unavailable. They succeeded in characterization of sinks and sources of the various natural and anthropogenic atmospheric contaminants. They contributed to the closing of a large gap in definition of global concentration of trace substances for incorporation into global models of net source and sink strengths of the various natural and anthropogenic atmospheric contaminants. The findings also contributed to:

- Design and development of the chemical personnel detector (SNIFFER) used in Vietnam after 1967 (and considered for the Sinai peacekeeping in 1976)
- Understanding of the mechanism for deterioration of material in the tropics
- Test and evaluation of material by the US Army Tropic Test Center
- Techniques for measurement of trace gases in the field
- Background measurements for pollution, air quality, and global monitoring for climatic change.

References:

Lodge, J. P., Jr. and Pate, J. B., 1966: "Atmospheric Gases and Particulates in Panama," Science, 153, 408-410.

Lodge, J. P., Jr., Machado, P. A., Pate, J. B., Sheesley, D. C., and Wartburg, A. F., 1974: "Atmospheric Trace Chemistry in the American Humid Tropics," Tellus XXVI, 250-253.

Miles, D. L., Pate, J. B., and Lodge, J. P., 1970: "Atmospheric Nitrous Oxide Concentrations in the Humid Tropics," J. Geophys Res., 75, p 2922-2926.

Polyphosphazenes

Professor H. R. Allcock, Pennsylvania State University, has found that polyphosphazenes, consisting of an inorganic backbone, high polymer system based on alternating phosphorous and nitrogen atoms, possess exceptional resistance to fuels, oils, and lubricants in addition to low temperature flexibility. The practical utility of the polyphosphazenes lies in the ease with which different side groups can be attached to the backbone. Because different side groups impart different properties to the polymers, materials with specific technological applications can be tailor-made. Polyphosphazenes are now used in nonburning gaskets, seals, O-rings, pipelines, and expanded foam applications where oil and solvent resistance and low temperature flexibility are critical properties. Future uses are envisioned in the areas of biomedical reconstruction plastics and nonburning textile fibers.

An excellent review of these materials entitled "Polyphosphazenes: New Polymers with Inorganic Backbone Atoms" by H. R. Allcock may be found in Science, *193*, 1214 (1976), which also lists the original references pertaining to this research.

Enzymatic Saccharification of Waste Cellulose to Glucose for Production of Useful Products

Cellulose, the most abundant organic material on earth, is used by man in industry, for structural purposes, textiles, and paper, but it does not serve as food for man or most animals. Research at the Army Natick laboratories on the decomposition of cellulosic materials by microorganisms has paved the way for the enzymatic breakdown of cellulose into a simple sugar-glucose. This process can have a significant impact on problems of the future relating to foods, energy, and chemical feed stocks, as shown by the following examples:

- Production of glucose from cellulosic waste. The glucose can be used directly as food for man and animals, or indirectly through the production of food yeasts.
- Improvement of texture, digestibility, and nutritive value of foods.
- Release of desirable products from plant tissues. Such products include leaf protein, drugs, essential oils, natural insecticides, olive oil, rubber, and agar.
- Use of the glucose as a chemical feed stock for the synthesis of diverse chemicals now utilizing petroleum as a raw material.

The following pamphlet reviews the work and includes published references: Ed. Mary Mandels, Edwin Reese, and Leo A. Spano, Enzymatic Conversion of Cellulosic Materials: Technology and Applications. 1976. An Interscience Publication.

Electron-beam (e-beam) Resist Materials for Integrated Circuits

In the Electronics Technology and Devices Laboratory at Ft. Monmouth, New Jersey, Drs. E. H. Poindexter and J. N. Helbert (in collaboration with Professor L. Kevan at Wayne State University) have been concerned with improving a beam-resist writing speed by factors of about 20 to 30, and attacking this problem at the most basic chemical level. The first approach was a systematic substitution of chemical groups along the main chain molecules of certain polymers, selected initially on the basis of potential applications tractability. Functional substituents such as halogens and cyanides were introduced to favor chain scission and discourage subsequent polymer self-healing via cross-linking. For this basic radiation chemistry, the techniques of electron spin resonance, viscometry, membrane osmometry, and gel-permeation chromatography were used to assess polymer degradation, i.e., sensitivity to the e-beam radiation. In addition, the physical chemistry of the resist solvent was studied by a unique low-field dynamic nuclear polarization technique. By these methods, basic science was brought to bear on a problem area heretofore treated largely on an empirical basis.

The program has so far resulted in discovery of several resists of substantially greater sensitivity, and in new solvent developers which have a very high differential dissolution ratio for further enhanced lithographic performance. The chlorinated resists developed from this research have an inherent e-beam sensitivity almost as great as the sulfone resists developed at Bell Labs, but are much more stable and tractable for use in production. In contrast to the sulfones, these resists are compatible with advanced radiation processing methods and have been adopted for production testing by Texas Instruments. Other potential industrial users (both in this country and abroad) have also expressed an interest in them.

The essential aspects of the program have been documented in eight technical papers, of which three are:

Increased Radiation Degradation in Methyl Methacrylate Copolymers, J. Appl. Polymer Sci. *19*, 1201 (1975)

Matrix ENDOR of Polyenyl Radicals in Polymers, J. Polymer Sci. (Polymer Physics Ed.) *13*, 825 (1975)

Poly(methyl a-chloroacrylate) as a New Positive Electron-Beam Resist, J. Electrochem. Soc. *124*, 158 (1977)

Pressure Oxidation of Silicon

Silicon, the principal semiconductor material used in the manufacture of discrete and integrated circuit components, must be subjected to a conventional high-temperature (1,200°C) thermal oxidation during device fabrication. It was widely recognized that high temperature induces structural defects and results in lower yield, performance, and reliability of the final device, and raises practical problems of device reproducibility and high cost. There has been strong motivation within the semiconductor industry for more than a decade to develop a lower temperature oxidation method for silicon integrated circuit devices, but a satisfactory process was not found.

An experimental system was designed and completed at the U. S. Army Electronics Technology and Devices Laboratory in which silicon wafers were successfully oxidized at 800°C (400°C lower than standard oxidation) and a pressure of 2,000 psi of oxygen (within commercial bottle-gas range). Scanning electron microscopy showed the oxide layers to be structurally homogeneous and

coherent. Electron spin resonance confirmed a lowering of defect concentration relative to oxides prepared conventionally. Measurements of flat-band voltage shift under bias-temperature stress, of surface state charge density, and of dielectric strength show values substantially better than those generally reported for conventionally grown oxides. Superior gate, field, and isolation oxides for a wide range of applications in integrated circuit devices (e.g., LSI digital devices for secure communications and other man-portable, airborne, or munitions delivery electronics) can be obtained in shorter processing times and at reduced oxidation temperatures by dry pressure oxidation.

The potential for reduced production costs is of interest to several major industrial electronic manufacturers, which have requested details from the Army on requisite instrumentation and processing techniques. Suitable pressure-oxidation equipment is being developed on a production scale for industry under Defense Advanced Research Projects Agency (DARPA) sponsorship. Research and device programs are being undertaken cooperatively with industry and academia.

Six publications and invited presentations have resulted from the program, three of which are:

R. J. Zeto, C. G. Thornton, E. Hryckowian and C. D. Bosco, Low Temperature Thermal Oxidation of Silicon by Dry Oxygen Pressure Above 1 Atm, J. Electrochem. Soc. *122*, 1409 (1975).

R. J. Zeto, C. G. Thornton, E. Hrychowian, and C. D. Bosco, Low Temperature Pressure-Oxidation of Silicon for Integrated Circuit Technology, Army Science Conference Proceedings, US Department of Defense, Vol. III, *413*(1976).

R. J. Zeto, High Pressure Oxides, Gordon Research Conference on Metal-Insulator-Semiconductor Systems, Kimball-Union Academy, Meriden, New Hampshire, August 1976.

The STRATCOM Program

The stratospheric composition (STRATCOM) program is a long-term, multipurpose program for integrated, correlated measurements of stratospheric parameters related to composition, thermodynamics, and radiative balance. It provides the means for the Army to obtain the necessary data base to develop and validate a chemical kinetic model needed to determine atmospheric effects on ballistic missile defense and communication systems. The program was initiated by the Atmospheric Sciences Laboratory at White Sands Missile Range (WSMR), New Mexico, in 1968 to take advantage of new developments in balloon technology which provided the capability to place a stable platform with 66 pounds of scientific payload at the top of the stratosphere (50 km) for a period of 24 hours (STRATCOM I). The obvious advantages offered through large balloon platforms quickly led to joint agency experiments of ever-expanding complexity and scope. STRATCOM VII, conducted at WSMR in September 1976, was sponsored by three Federal agencies and involved experimenters from 10 laboratories (Government, university, and private industry). More than 20 on-board instruments measured atmospheric composition and structure for 34 hours in the altitude range of 23 to 39 km. In addition, supporting measurements were made with sensors on rockets, small balloons, and satellites. Joint sponsorship and funding for the STRATCOM program allows for a more comprehensive program than could be achieved by any single organization. The scientific value and cost effectiveness are now well known; the program description was included in briefings to the United States Senate Subcommittee on the Upper Atmosphere and is part of the *Congressional Record.* A special session of the American Geophysical Union national meeting in December 1974 was devoted to STRATCOM III and STRATCOM IV, and a session for STRATCOM VII was held in May 1977.

References:

Hearings before the Subcommittee on the Upper Atmosphere of the Committee on Aeronautical and Space Sciences, United States Senate, Ninety-Fourth Congress, Second Session, February 25 and March 1, 1976.

Randhawa, J. S., 1969: "Ozone Measurements from a Stable Platform near the Stratopause Level," J. Geophys. Res., 74, 4588-4590.

Ballard, H. N., et al., 1970: "A Constant Altitude Balloon Experiment at 48 Kilometers," J. Geophys. Res., Vol 75, No. 18, 3501-3512.

Beyers, N. J., and B. T. Miers, 1970: "Measurement from a Zero-Pressure Balloon in the Stratopause (48 km)," J. Geophys. Res., 75, 3513-3522.

Ballard, H. N., et al., 1972: "Atmospheric Tidal Measurements at 50 km from a Constant Altitude Balloon," J. Appl. Meterol., Vol II, No. 7, 1138-1149.

Ballard, H. N., 1976: "Temperature Measurements in the Stratosphere from Balloon-Borne Instrument Platforms, 1968-1975," ECOM-5808, Proceedings Ninth AFGL Scientific Balloon Symposium, October 1976.

Thermomechanical Treatment of Aluminum Alloys

A U.S.-Italy cooperative research program on aluminum alloys was performed over the period of 1968-1975, the objective of which was to study the effects of alloy composition, ingot solidification techniques, homogenization, and complex combinations of plastic deformation and thermal treatments on properties of aluminum alloy ingots.

A significant accomplishment of the program was that two new thermomechanical treatments (TMT) resulted for high-strength aluminum alloys. The importance of this accomplishment is that 7XXX ("seven thousand") series aluminum alloys, which are major "work-horse" structural alloys, can now be produced having superior combinations of properties (strength, ductility, toughness, and fatigue and corrosion resistance) unmatched by existing commercial alloys. Follow-on development, and manufacturing methods and technology programs have developed TMT for thicker sections through in-house efforts at Frankford Arsenal and contractual efforts at Alcoa and Boeing Vertol, for such applications as lightweight armor and helicopter forgings.

The in-house research effort was performed at the Pitman-Dunn Labs of Frankford Arsenal, and the Italian program was funded through the Army's European Research Office.

Patents:

3706606: E. DiRusso and M. Conserva, Thermomechanical Treatment Procedures for Heat Treatable Aluminum Alloys.

3743549: E. DiRusso, M. Buratti and M. Conserva, Thermomechanical Process for Improving the Toughness of High Strength Aluminum Alloys.

Publications:

E. DiRusso, M. Conserva, F. Gatto, and H. Markus, Thermomechanical Treatments of High Strength Al-Zn-Mg (Cu) Alloys, Met. Trans., Vol 4, April 1973, pp 1133-1144.

E. DiRusso, M. Conserva, M. Buratti, and F. Gatto, A New Thermomechanical Procedure for Improving the Ductility and Toughness of Al-Zn-Mg-Cu Alloys, Materials Sci. and Eng., April 1974, Vol 14, No. 1, pp 23-26.

New Classes of Permanent Magnetic Materials

Research by W. E. Wallace and R. S. Craig at the University of Pittsburgh sponsored by the U.S. Army Research Office on the magnetic properties of a class of compounds called rare earth intermetallics has been coupled with military and industrial research and development to result in a new group of materials for permanent magnets. The most powerful of these, a compound of samarium and cobalt (called SAMCO), has a magnetic energy product (a measure of the magnetic strength of a permanent magnet) five times that of the best conventional permanent magnets. This high-energy product allows large reductions in size and weight with improvement in performance reliability. The Army currently uses these magnets in engine alternators for helicopters, and they are projected for use in the guidance system of the SAM-D missile. Other potential Army applications include electrical generators and motors, fuses, and fuel cell components.

References:

Proceedings of the 12th Rare Earth Research Conference, July 18-22, 1976, Vols 1 and 2.

W. E. Wallace, Rare Earth Intermetallics, Materials Science Series, Academic Press, Inc., 1973.

E. A. Nesbitt and J. H. Wernick, Rare Earth Permanent Magnets, Materials Science Series, Academic Press, Inc., 1973.

Research on Fluidics

The capability to use fluidics in high performance systems has been enhanced significantly by research on the laminar proportional amplifier (LPA) conducted at the Harry Diamond Laboratories (HDL). Fluid mechanics techniques from first principles were used to investigate the flow phenomena in fluidic components. Expanded experimental facilities were used for flow visualization, and dynamic and transient response measurements of the LPA. Computer codes were investigated for developing algorithms.

The initial LPA study was reported in 1972 by HDL scientists. The first use of the developed algorithms for system design was reported at the American Society of Mechanical Engineers winter meeting in 1975, and the algorithms became universally available in 1976. These algorithms, along with circuit techniques, were used to reduce the temperature sensitivity of hydraulic fluidic systems. The close coupling of fluidic research and system needs resulted in the use of LPA's in advanced military applications such as the UTTAS helicopter and in current development efforts on gun stabilization and turbine fuel control. These precision control devices are now commercially available, and projected use in temperature monitoring systems may save considerable energy in process control.

Military savings of $20 million have already been achieved, and the potential savings could easily exceed the total amount of R&D dollars that have been expended in fluidics.

References:

Carter, V. and Marsh, D. S., HDL-TR-1495, A Bibliography on Fluidics, Revision B, April 1972.

Proceedings of the Fluidic State of the Art Symposium, September-October 1974, Volumes I-VI.

Fleming, W. T. and Gamble, H. R., HDL-CR-76-092-1, Reliability Data for Fluidic Systems, December 1976.

Joyce, J. W., Manufacturing/Production-Line Applications of Fluidics, October 1975.

Dynamic Stall on Airfoils Oscillating in Pitch

The Army Air Mobility Research and Development Laboratory investigated the effects of dynamic stall on airfoils oscillating in pitch by experimentally determining the viscous and inviscid characteristics of the airflow on several airfoils. As a result, a new understanding of the flow environment on an oscillating airfoil, and, in particular, the relationship between boundary-layer behavior and normal-force and pitching-moment behavior was obtained. An important result of this study was that a properly scaled cross-plot of normal force versus pitching moment resulted in a single representative curve for each airfoil, provided the vortex had fully developed. This introduces the possibility of a method that may allow prediction of engineering parameters without exhaustive dynamic testing of airfoils.

References:

W. J. McCroskey, L. W. Carr, and K. W. McAlister, Dynamic Stall Experiments on Oscillating Airfoils, AIAA Journal, Vol. 14, No. 1, January 1976.

L. W. Carr, K. W. McAlister, W. J. McCroskey, Analysis of the Development of Dynamic Stall Based on Oscillating Airfoil Experiments, NASA TN D-8382, January 1977.

Physical Properties and Processes in Frozen Ground

Effective Army operations in cold regions are constricted in a significant way by the limitations imposed on mobility and facilities by snow cover, frozen ground, and freeze-thaw conditions. As part of its basic mission, the Army Cold Regions Research and Engineering Laboratory (CRREL) has continuously advanced the state of the art in these areas. In particular, mechanical properties such as strength, deformation, and creep have been examined using modern techniques and equipment. This has led to extremely useful advances in the understanding of unfrozen water and the part it plays in the physics of the microstructures as a function of temperature. The migration of unfrozen water to the advancing or retreating freezing front provides valuable insight into the understanding of the behavior of pavements and foundations in freeze-thaw cycles.

This technology has been applied to the solution of critical foundation problems such as those on safeguard missile sites and piles used in the Alaska pipeline. The study of thermophysical processes in permafrost has assured successful environmental protection schemes in the retrieval of northern oil resources. Significant advances have been achieved in the subsurface exploration of Arctic and subarctic terrain as a result of CRREL studies of the dielectric behavior of frozen ground coupled with a theoretical analysis of titled electromagnetic waves traveling along the earth's surface.

References:

Haynes, F. D. and Mellor, M., Measuring the Uniaxial Compressive Strength of Ice - International Glaciological Symposium, Cambridge, England, September 1976, Proceedings.

McGaw, R. W. and Tice, A. R., A Single Procedure to Calculate the Volume of Water Remaining Unfrozen in A Freezing Soil - Second Conference on Soil - Water Problems in Cold Regions, Edmonton, Canada, 1-2 September 1976, Proceedings.

Tobiasson, W. and Gianotti, J., Design Data for Construction in Alaska - Second International Symposium on Cold Regions Engineering, University of Alaska.

Mellor, M., Engineering Properties of Snow - Symposium on Applied Glaciology, Cambridge, England, September 1976, Journal of Glaciology.

Sellman, P. V., Arcone, S. and Delaney, A., Preliminary Evaluation of New LF Radiowave and Magnetic Induction Resistivity Units - Over Permafrost Terrain, Vancouver, British Columbia, Canada, October 12, 1976.

A New Simulation Approach for Combat Training

REALTRAIN, or realistic training, is a new, successful, and very much accepted approach for training U. S. combat forces. Upon completion of basic and advanced combat training, which is intended to impart the necessary combat skills to the individual soldier, it is necessary to embark on team training designed to weld the combat units into effective entities. REALTRAIN represents an innovation replacing current approaches utilizing field training exercises and maneuvers for this purpose. The older methods depend on referee determinations and judgments to assess casualties in the conduct of the combat exercises. These approaches by their very nature are cumbersome and prone to substantial error in casualty assessment, thus reducing much of the effectiveness of the training. REALTRAIN permits a soldier definitively to identify his target and provides immediate and reliable feedback concerning the inflicting or sustaining of casualties in simulated two-sided free-play combat engagements. It is a method far superior to those used heretofore. REALTRAIN itself is projected to be augmented by MILES, which relies on weapon-mounted laser devices coupled to highly sophisticated instrumentation to permit free-play engagement with minimal interference on the part of referees. Simultaneously it will facilitate the recording of the necessary data and provide immediate casualty assessment feedback to the exercise participants without intervention by exercise controllers.

The evolution of both the REALTRAIN and MILES systems can be traced to considerable

basic research concerned with systems, system development, and system measurement.

As early as the late 1950s, the Army Research Institute (ARI) had embarked on a then-new area of research dealing with systems. At the heart of these efforts was the recognition that results based on research conducted in a static environment possess only limited utility concerning decisions with impact on combat effectiveness. In a report on image systems (1), an approach to systems research was conceptualized which considered such factors as the structure and function of systems expressed in terms of Army needs. Of particular interest was system assessment, which considered such factors as subsystem versus total system criteria; the concept of the simple systems (or existing systems) as standards against which to assess new, more sophisticated systems; and the problem of system performance measurement in terms of a multivariate, rather than a univariate, criterion. The multivariate criterion is significant because it permits trade-offs among the dependent variables, as well as among the independent variables. This is particularly important to decisionmakers who must choose a system alternative, since the output dimensions could influence discussions about system configurations and procedures.

Upon recognition of the complexity of systems research, considerable basic research effort was expended to develop further the concepts of systems research (2,3,4) and simultaneously to develop the supporting tools for such research, including both methodology and instrumentation. Thus, considerable research was done on the development of measurement systems such as the surveillance systems measurement bed (5) technology and field research instrumentation (6), and a measurement setting for the assessment of small unit effectiveness (7). These measurement beds were designed to permit the assessment of systems, subsystems, or components within a context simulating real-world conditions as much as possible to accommodate for the measurement of the important interaction effects. The development of these measurement beds imposed the need for a proper sampling of the significant tasks and the opportunity for the experimental subjects to execute the tasks in a realistic manner free from inappropriate intrusions such as those associated with data collection. (The recording of data, if not a normal part of the subject task, is an example of such intrusions.) It is this focus of basic research that led to the development of dynamic, realistic, highly instrumented measurement beds which in turn give rise to the development of REALTRAIN and MILES. REALTRAIN and MILES merely reflect a translation of the realism and instrumentation in test and evaluation to that of training and thus are direct beneficiaries of the basic research on system assessment.

References:

(1) Birnbaum, A. H., TRN 122, Human Factors Research in Image Systems Status Report, 30 June 1962.

(2) Uhlaner, J. E. et al., TR S-1, Psychological Research in National Defense Today, June 1967.

(3) Uhlaner, J. E., TR S-2, Human Performance Jobs, Jobs, and Systems Psychology—The Systems Measurement Bed, October 1970.

(4) Uhlaner, J. E., TR S-3, Management Leadership in System Measurement Beds, August 1975.

(5) Birnbaum, A. H., et al., TRR-1160, Summary of BESRL Surveillance Research, September 1969.

(6) Hyman, A. et al., TRN 223, Human Performance Experimentation in Night Operations: Technology and Instrumentation for Field Research, June 1970.

(7) Sternberg, Jack, J., et al., TRN 237, Effects of STANO Sensors on Small Unit Effectiveness-Part I, January 1972.

Similarly, the Army has many interesting research projects that are currently in progress. Five such projects are listed below.

Drug Development Program

The drug development program is a multidisciplinary, intra- and extramural research effort coordinated and managed by Walter Reed Army Institute of Research. Rather than the usual empirical search for efficacious drugs, this program includes a computer-assisted rational search for new drugs. Synthesis of candidate new drugs is based on structural relationships with known agents; efficacy is screened through several biological systems. Further studies on toxicology, pharmacology, metabolism, and pharmacokinetics are designed to lead in planned sequence to eventual clinical trials. This effort was originally directed toward treatment of drug-resistant falciparum malaria, but its goals have recently been broadened to begin the search for new drugs effective against other diseases of military importance.

Submillimeter Wave Research

Relatively recent advances in the development of sources and detectors have stimulated a parallel interest within several Army laboratories in submillimeter technology. Some of the recent scientific advances have included research on the optically pumped far infrared laser, Schottky barrier detection, and relativistic electron-beam generation of electromagnetic waves. At the same time,

there has arisen an increased awareness of the potential of enhancing imaging and sensing under normally obscured visibility by using submillimeter techniques. Consequently, there has been increasing activity in research on coherent sources, propagation, and detection as part of a coordinated Army-wide program. Contractors participating in the program are the Georgia Institute of Technology and Lincoln Laboratories. In-house work is in progress at the Army Missile Command, Harry Diamond Laboratories, and the Army Electronics Command.

Research on Percolation Theory

Percolation theory is a computer simulation technique which permits prediction of the distribution of phases in multiphase systems, and thereby mechanical, electrical, and thermal properties of alloys and a wide variety of composite materials.

Thus far, the results of in-house efforts at the Army Materials and Mechanics Research Center have been beneficially applied toward the prediction of optimized structures of materials for a host of diverse end uses, such as gradient armor, reduction of blast damage, and noise suppression (e.g., optimum pore structures in foamed materials). Further improvements in the technique and applications of the technique are in process.

Reference:

"Phase Connectivity in a Two-Phase Microstructure Monte-Carlo Calculation of Topological and Percolation Properties", George D. Quinn, George H. Bishop, and Ralph J. Harrison, Pub. in Nuclear Metallurgy, 20, 1215-1225, 1976. The Proceedings of 1976 International Conference on Computer Simulation for Materials Applications, NBS, April 1976.

Pulsed Positive Negative Ion Chemical Ionization Mass Spectrometry

Conventional mass spectrometry, a technique based on the generation of positive ions by the impact of electrons upon a vaporized sample, has long provided the most effective way to identify complex chemical compounds. The ions in general acquire considerable energy in the course of their formation, and as a result rapidly undergo extensive fragmentation, limiting the amount of structural information obtainable in the analysis. In the chemical ionization approach, electron transfer to form sample ions occurs in an indirect manner: Ions are formed by electron impact upon relatively stable gases, which then transfer electrons to or from the sample molecules. Less excess energy is present, and comparable concentrations of positive and negative ions are produced.

Professor Donald F. Hunt of the University of Virginia, a pioneer in the development and application of the chemical ionization technique, has succeeded in coupling it with an effective means to detect positive and negative ions simultaneously. This he has accomplished by using conventional electrostatic techniques to draw alternate bursts of positive and negative ions from the ionization chamber, and then analyzing the beam with a quadripole filter. Two matched electron multipliers, one each for positive and negative ions, allow simultaneous display of each signal as a function of ionic mass (or more correctly, mass/charge ratio). The instrumentation and its use have been described and its potential assessed in detail.

The reduction in ion fragmentation, the enhanced generation of negative ions, and the added information provided by the analysis for both positive and negative species, provide a dramatic improvement in the diagnostic capability. This is accompanied by a hundred-to-thousand-fold increase in sample ion current at the detectors, translating into an increase in sensitivity to the 10^{-12} or 10^{-13} gram level. The basic technique is being further developed for the detection, identification, and quantification of volatile and nonvolatile organic and inorganic substances at the nanogram (10^{-9}) to femtogram (10^{-15}) level.

Remote Sensing of Wind and Atmospheric Structure by Lidar

Dr. J. A. Weinman and his group at the University of Wisconsin have developed a high resolution monostatic lidar (laser radar) system for probing the lower atmosphere. Light pulses from the lidar are scattered from aerosols which occur naturally in the atmosphere boundary layer. The time that elapses between the emission and return of this light is used to determine the range at which the aerosols are located. The magnitude of the return signal has been determined to be proportional to the densities of aerosols at that range. The aerosols are not uniformly distributed in the boundary layer, and the motion of these natural aerosol density inhomogeneities can be tracked. Measurement of the rate of displacement of the inhomogeneities renders it feasible to measure wind remotely in near real time. By changing the lidar elevation and digitally processing the data, near real time vertical cross-section displays of optically "clear" atmospheric convection can be made visible, and such diverse atmospheric structures as inversions, convective plumes, incipient clouds, and waves are observable. Time series of such pictures permit the complex motion field under cumulus clouds to be observed. Thus, atmospheric structure and wind can be obtained on a time scale and resolution not feasible with current meteorological observation systems.

References:

Kunkel, K. E., Eloranta, E. W. and Weinman, J. A., 1977: "Visualization of Eddies in the Planetary Boundary Layer by Means of Lidar," Quarterly Journal of the Royal Meteorological Society (to be published).

Eloranta, E. W., Kubg, J. M. and Weinman, E. W., 1975: "Determination of Wind-Speed in the Boundary Layer by Monostatic Lidar," Journal of Applied Meteorology, 14, 1485-1489.

Current and Future Research Emphasis

During FY 1977, six critical topics have been designated as Army science and technology areas of emphasis to respond to high-priority Army user needs and to indicate to Army laboratories where research is especially needed. These areas will be emphasized in the Army's research program during the next three years.

- One area is millimeter (mm) and submillimeter (submm) wave radiation, which can penetrate fogs and battlefield smokes. The Army is seeking new generators, detectors and tuning componentry in mm and submm and is studying propagation and factors affecting imaging.
- In smokes and aerosols, the Army is investigating the effective use of smokes to obscure friendly operations while allowing freedom of mobility and targeting capabilities.
- A more comprehensive compilation and analysis of target and background signatures is required to ensure effectiveness of our guided weapons in smokes, dusts, and inclement weather.
- Requirements for higher muzzle velocities, longer ranges and higher rates of fire have magnified gun tube wear and erosion problems. The Army is taking steps to assure that wear and erosion research will be responsive to short-and long-term needs.
- Reliable analytical and predictive techniques are required for improved armor design and development of effective penetrators for armor penetration. This complex problem requires a well-coordinated program in mechanics and materials sciences.
- Recent gun charge design problems also highlight the need for a comprehension of the processes of ignition and combustion of gun propellants. These efforts are intended to predict and control the response of propellants by evolving models for prediction of ignition and burning rates.

Program priorities for the next 10-year time period have also been established. Fifteen such "thrust areas" are described below:

Atmospheric sciences research contributing to the Army smoke program. The use of smokes to accomplish many apparent military objectives necessitates fundamental research in four atmospheric disciplines. First is cloud and aerosol physics, for better understanding of nucleation and growth processes and more complete knowledge on particle size spectra, shape, composition, and distribution. Second is the transmission properties of the natural or manmade atmospheric aerosol, for a detailed understanding of absorption and scattering of electromagnetic signals, particularly in the infrared and optical ranges. Third is remote sensing of atmospheric aerosol and properties necessary to the prediction of transport and dissemination of aerosols. Fourth is consideration of small-scale atmospheric processes which are dependent on interaction of the atmosphere and terrain and have an important effect on the life cycle of an aerosol. The importance of integrating these diverse disciplines in an overall smoke program must be stressed.

Food and ration research. This thrust area, food and ration research, supports the Army Tri-Service food mission. Subtopics include food microbiology, irradiation, preservation, postharvest physiology of fruits and vegetables, time-related changes in meat, physiological parameters in food acceptance, and pest control. There are 15 work units currently funded. These range from studies on basic protein structure of storage protein in soybeans, ionizing radiation damage and repair in bacterial spores, and factors in fruit spoilage to new approaches to pest control through use of pheromones and control of genetic factors in insects. The work supported will have a large aggregate contribution to simplification or reduction of logistic factors in future support of field armies.

Electrically small, active antennas. The Army has a requirement for shorter, less visible antennas on tanks, vehicles, and manpacks. Research in the field of antennas is performed to understand basic limitations of antenna radiation characteristics when the geometry of the antenna is substantially smaller than the respective wavelength to be radiated. Schemes to incorporate amplifiers into the antenna structure to obtain active antennas are investigated. Active electronic means are considered to improve band width and efficiency of these antennas. Low-profile, printed circuit antennas are investigated for their potential use as conformal antennas on Army equipment. The ultimate objective for manpack antennas is to enable the operator to communicate in any terrain over distances up to 10 miles without being detected.

Wear and erosion. Research to explain, predict, and prevent deterioration of materials undergoing impingement by hot gases or particulates is urgently needed. The Army's gun tubes, and rocket, missile, and aircraft turbine components are seriously and adversely affected by hot gas erosion. Dust erosion of helicopter rotors and rain erosion of missile radomes, are also severe problems. Mechanisms of erosion are neither well-defined nor understood; solutions for erosion problems have been largely based on empirical techniques, and have addressed specific combinations of materials, geometrics, and operating conditions (e.g., in hot gas erosion, gun tube steel, chamber configuration, projectile, propellant chemistry, pressure, and temperature). The development of quantifiable parameters is required for rational approaches to avoid or inhibit wear and erosion. Analyses in the hot gas area are complex and must be based on interdisciplinary approaches embodying such diverse areas as thermometallurgy, deformation and fracture criteria, inorganic chemistry, fluid dynamics, and safe life prediction.

Mathematical analysis of nonlinear systems. The principal thrust of the mathematics program is on the analysis of nonlinear systems. A significant component of this thrust is on the study of the qualitative features of the basic equations of classical applied mathematics which continually arise in many Army problems such as heat transfer in gun tubes, elastic-plastic analysis of structures, penetration mechanics, and aerodynamics, among others. Because these problems, in general, do not lend themselves to closed-form solutions, considerable effort is directed toward the development of approximate, numerical, and statistical methods for solving nonlinear systems including nonlinear partial differential equations, nonlinear optimization models, and nonlinear filtering and estimation problems.

Dynamic loading of structures and materials. This major research program is concerned with devising the principles for predicting the deformation and failure of structures and materials under dynamic loads. Strong Army interest in this research field arises due to weapon effects, armor defeat, projectile impact, fragmentation, explosive detonation, and aeroelasticity. Characteristic times of these loadings vary from microseconds to tens of milliseconds, illustrating the broad range over which any phenomenological model must be applicable.

Improvement of helicopter performance. A major research program concerned with the improvement of rotorcraft performance is concentrated on those pacing problem areas identified by field experience and future air mobility objectives. Investigations are concerned with such areas of interest as dynamic stall, strongly interacting flows, aerodynamic drag, rotor downwash and its effects, rotor-generated noise, aerodynamic stability, and bluff body aerodynamics. Investigations in these basic problem areas contribute to the technology base required for making design studies for specific performance requirements of future rotorcraft.

Combustion processes in engines and propellants. Research thrusts in the general field of combustion are necessary to support Army requirements for efficient propulsion of weapons and air or ground vehicles. The understanding of combustion processes requires investigations on propellant ignition, flame propagation and stability, gas dynamics, chemical kinetics, detonation and deflagration, thermodynamics, and materials. The basic energy source, either propellant or fuel, requires a fundamental examination as to such characteristics as stability, ignition or flash point, fire safety, thermal capacity, aging processes, and the energy release mechanisms.

Submillimeter technology. The Army's interest in submillimeter technology is for imaging radar and other applications. Emphasis is currently being placed on obtaining information that would make possible sensitive, compact detectors that operate at room temperature (Schottky barrier). The development of high-power coherent sources is also a priority in this program. Current efforts include the investigation of optically pumped submillimeter lasers. A small effort is being devoted to the characteristics of compact electron beam pumped devices. It is expected that this thrust area will be expanded, particularly with regard to source and detector research. Several unusual approaches are currently being considered for inclusion in the program.

Fire safe fuels. This thrust area is concerned with fuel mist flammability and the mechanism by which certain additives can inhibit the ignition of fuel sprayed or spewed into the atmosphere as the result of the rupture of a fuel tank. Four work units are currently underway, each examining the basic questions from a different perspective. One concerns mist flammability under initially nonturbulent conditions, and the effect of varying the speed of flame propagation. The rest address questions at a molecular level: the reaction with oxygen of free radicals implicated in the initial step, the intervention of halocarbon radicals or of halogen atoms in inhibiting processes, the rates of the various chemical reactions, and the identification of intermediate species by mass spectroscopy or matrix isolation infrared absorption spectroscopy.

Armor penetration. The interaction of kinetic

energy penetrators and armor are vitally important phenomena which are not well understood. At present a comprehensive theory of penetration does not exist. Although great strides have been made in the generation and use of both sophisticated computer simulations and simpler engineering models, they all involve empirical correlation of input and output data. While essentially empirical prediction techniques are useful, greater progress in both penetrator and armor design will be made when reliable analytical prediction capabilities are available. This complex, interdisciplinary problem involves a variety of deformation and failure mechanisms in both the penetrator and the armor. A basic research program involving both mechanics and material sciences is needed in this area.

Materials research. More than 65 percent of advanced weapons system failures are materials failures. To counter the penalties due to such failures, the Army conducts a broad-based materials research program directed toward four generic weapon system areas: Aircraft, armament, armor, and missiles. The objective is to develop and characterize materials to provide weapon system cost reduction, improved performance and reliability, and reduced maintainability for new and improved weapon systems. Current weapon system deficiencies include need for improved armor for advanced ground combat vehicles, need for improved munitions to defeat advanced armor, need for high-strength, lightweight materials to reduce the costly accelerated wear of helicopter transmissions and gears, and the need for advanced high temperature ceramics for Army gas turbine engines. The Army will apply increased resources and emphasis to these deficiences and will exploit technological opportunities for providing cost effective, reliable, and maintainable weapon systems for the modern field Army.

Medical research. The loss of military manpower resulting from combat casualties, injuries, and disease has represented a large cost in both trained manpower and rehabilitation and treatment costs. Medical R&D programs are being conducted to reduce manpower and treatment costs through avoidance of environmental injuries, prophylaxis, and improved procedures for treatment of casualties. Particular emphasis will be given in these programs to combat surgical techniques, environmental injuries, performance and stress prophylaxis to protect troops against disease, and defense against biological and chemical agents.

Organizational effectiveness. A priority requirement is the development of organizational effectiveness to improve quality and competence of officer and enlisted personnel and performance of Army organizations. A new research thrust is required to develop tools, methods, and techniques that will assist Department of the Army major commands and individual units in identifying, handling, and evaluating organization problems and solutions. Examples include unit attrition, individual and unit mission readiness, individual and unit training requirements, developing job designs and redesigns to handle new tactics and weapon system installations and usage, logistical and maintenance systems, and the range of personnel, supervisory, and workload factors that degrade individual and unit performance.

Ice adhesion. The adhesion of ice to surfaces, such as power lines, antennas, communication towers, ships, military ground equipment, helicopters, and pavements, still remains one of the biggest, only partially solved, problems in cold regions research. The difficulties concentrate largely in industrialized areas south of the advancing polar air masses. An icing storm can substantially affect missile defense systems or impede military operations in Europe. This consideration has prompted an intensified attack on basic research problems in this field, in cooperation with universities. The surface chemistry of ice and substrate is being examined, including crystallographic defects and dielectric aspects. The potential of surface coatings and physical or chemical treatment is being examined. Climatological criteria leading to difficulties are being derived. Experiments on the icing of rotating elements have been conducted in a laboratory and under most difficult conditions in the field. Theoretical models are being developed that show the icing potential as a function of the relevant physical parameters involved. Work is needed to find the correct effect of windspeed.

Although the Army has an extensive research program spanning almost the full spectrum of science and technology, and tries to support meaningful research in every area considered vital to its needs, there are a few important areas in which the Army has been directed not to have a research effort. For example, in the areas of drug abuse, venereal disease, and basic immunology, the Congress has enjoined the Army from conducting research. This is believed wrong, since drug abuse and venereal disease in military populations constitute unique problems in which further research is required, and basic immunology is a vital building block in any program of research toward prevention of infectious disease. Renewed emphasis on non-goal-oriented basic immunology is necessary to ensure availability of required tools and expertise to solve scientific problems of importance to the Army.

Organization and Management of Scientific Activities

The management cycle for the Army's research and development program including requirements, program initiation, review, and evaluation is accomplished on an annual basis. More specifically, the Army staff annually prepares and distributes to Army laboratories a user-oriented document called the "Science and Technology Objectives Guide" (STOG). This guide provides the Army research and development community with clear and concise descriptions of the Army's concept for future military operations, the deficiencies or short-comings of current systems, and the equipment and manpower capabilities required to meet the Army's needs. The STOG lists, as concretely as possible and in priority ranking, the Army's science and technology objectives, the user proponents for these objectives, and the laboratories responsible for coordinating the research and development.

In response to STOG guidance, laboratory scientists and engineers propose science and technology programs. These are reviewed at the laboratory level by the laboratory technical director. Proposed laboratory programs are then submitted through channels for review at command/staff levels. Also, management summary sheets (MSS's) delineating work actually being performed in all laboratories are prepared to show the effort addressing each of the science and technology objectives. The MSS's permit an across-the-board examination and evaluation of the science and technology base program in terms of requirements and program thrusts and emphases.

In March and August of each year, the Research, Development and Acquisition Council (RDAC), composed of senior Army personnel, reviews the orientation of the science and technology base program in terms of major thrusts and areas of emphasis. The RDAC considers the work being done to address pacing problems and the distribution of funds. The objective of this review is to identify critical issues and determine a science and technology base program. Army policy is to maintain an adequate in-house capability so the Army will be a smart buyer, to encourage and ensure investigation of new ideas and concepts that may contribute to the Army mission, and to maintain effective contact between the Army and scientists of the United States and, when appropriate, other nations of the free world.

Money is provided for support of research proposals submitted by scientists and engineers in other Government agencies, universities, industry, and nonprofit institutions. Each such proposal is evaluated by scientific peers for scientific quality and relevance to Army requirements. Current funding limitations permit supporting only the most outstanding proposals that also satisfy the relevance requirement. The Army research program is accomplished approximately one-half in-house and approximately one-half through research contracts and/or grants. Decisions in specific cases depend on capabilities and availability of resources in terms of personnel, equipment, and facilities.

Basic research efforts are initiated in two ways—scientists and engineers in Army laboratories and by scientists and engineers outside the Army organization. Although guidance is provided for the research program in general terms, responsibility for the content of the in-house basic research effort has been delegated to each technical director of an Army laboratory, and each is responsible for the initiation and termination of basic research tasks in the laboratory. The initiation of an external basic research effort depends on the evaluation of a proposal as to quality and relevance, and the availability of funds. The support of a contract or grant is normally for a specified period of time such as three years. A contract or grant for basic research is seldom terminated before the specified time period has elapsed, unless the principal investigator dies or for some other reason cannot complete the investigation. The renewal of a contract or grant (i.e., the support of a new contract or grant with the same investigator) depends on an evaluation of past performance and the pertinence of the new proposal at the time of its consideration.

The Army is sensitive to the importance of protecting research, and generally supports the science and technology base program including research on a level-of-effort basis. Current policy is to support the research program at approximately 5 percent of the total research, development, test, and evaluation program, and to implement approximately half of these funds through contracts and grants. So although a definite effort is made to establish an appropriate level for support of the research program and then "fence" these funds, it is not always successful. For example, during the Vietnamese effort the pressure of responding to urgent requirements and supporting U. S. troops in the field, combined with inflation, did erode the Army's basic research program. Current efforts and the current trend are to restore the support of basic research to the pre-Vietnamese level.

DEPARTMENT OF THE NAVY

The Mission of Naval Research

The mission of the research program of the U. S. Navy is to plan, procure, and encourage scientific research because of its paramount importance to the development and maintenance of future naval power and the preservation of national security. The principal focus of the resources of naval research is the Office of Naval Research (ONR) in accordance with the Act of Congress of August 1, 1946, Title 10 U.S.C. 5150-5153 (originally Public Law 588). The relevant language reads:

> The Office of Naval Research shall perform such duties as the Secretary of the Navy prescribes relating to:
>
> (1) The encouragement, promotion, planning, initiation, and coordination of naval research;
>
> (2) The conduct of naval research in augmentation of and in conjunction with the research and development conducted by the bureaus and other agencies and offices of the Department of the Navy, . . .

Accordingly, the charge to ONR is to exercise leadership in carrying out this mission and to provide within the Department of the Navy a single office, which by extramural contract and through its laboratories, shall be able to obtain or develop, coordinate, and make available to all activities of the Department of the Navy, worldwide scientific information and the necessary services for conducting the requisite specialized and imaginative naval research.

Definition of Basic Research

In the context of the ONR mission of naval research, we define research to include the scientific study and experimentation directed toward increasing knowledge and understanding in those fields of the physical, engineering, environmental, biological-medical, and behavioral-social sciences bearing on long-term national security needs. Such research provides fundamental knowledge for the solution of military problems; it also supplies part of the base for subsequent exploratory and advanced developments in defense-related technologies such as communications, detection, tracking, surveillance, propulsion, mobility, guidance and control, navigation, energy conversion, materials, structures, and personnel support.

Role of Basic Research

The management of the research program in the U. S. Navy has some unusual features compared to the programs in most Government agencies. After 1945, the usefulness of science and technology to the Navy was no longer in question. What remained to be determined was how best to arrange for the introduction of new science and technology, as they evolved, into Navy practice and equipment. Congress, in establishing the Office of Naval Research, foresaw the value of a single, central office within the Navy that would coordinate Naval research as well as conduct it. Implicit in this dual function was a staff made up of scientists who could absorb and appreciate advances at the frontiers of science while, at the same time, appreciating the technological needs of the present and future Navy. The staff of research managers has in fact been composed of members of the scientific and technological communities, as evidenced by their participation in professional societies, the number of professional publications they have produced, and the patents they hold. Experience over the past 30 years has shown the wisdom of this arrangement. The management style and practices developed by ONR have had a demonstrably favorable influence on advances in science and on naval technology. Several sorts of activity characterize the way the Navy's basic research managers carry out their jobs.

Funding basic research in areas that have immediate and obvious bearing on naval operations needs no elaboration. Navy-sponsored research in oceanography, hydrodynamics, and acoustics are well-known and constitute clear examples of mission-oriented scientific work of broad naval interest.

Not much more difficult for the research manager to select for support is research in fields of great, but not dominant or exclusive, Navy interest. Examples of accomplishments in such fields are:

- A program of research in the atmospheric sciences produced a method for the dissipation of fog from airfields.
- Research in metallurgy resulted in the development of refractory metals and alloys essential to the development of high-performance military and civilian platforms.
- Early ONR recognition and funding of the emerging fields of mathematical statistics and operations research ensured the important contribution of these disciplines to the con-

struction of a theory of inventory control and to providing a scientific underpinning to logistics decision-making.

The point of these examples is that the Navy has recognized that its own interests as well as those of society at large depend in one degree or another on the health of basic science. The Navy's research managers are therefore alert to the emergence of new technologies and advances in science even when these are not immediately recognizable as having naval utility. Frequently enough, spinoff useful to the Navy emerged from such advances. How does the manager become aware of new developments? One principal route is through the thousands of unsolicited proposals which pour into ONR annually. These provide important clues regarding what the scientific and technological communities consider to be currently worth doing. They also provide clues about new and able scientists coming into the research arena. Some proposals will deal with matters on the front lines of science. Such research often provides the scientific capital on which technology will eventually draw. Dr. Harold Brown, then Director of Defense Research and Engineering (DDR&E), in a speech at MIT in 1965, said that his experience led him to believe that, in Defense matters, the value of basic research as measured by its utilization could be determined in 10 years or less.

The second principal route is through attention to forums for scientific exchange. These include the relevant literature, attendance at national and international meetings and workshops, and conversations with scientists in their home laboratories or when they visit the Navy. In matters of current and pressing interest the research managers may mount their own symposia or workshops to determine the state of the art and adjust their programs accordingly. Negative research results have, on occasion, proved useful in aborting expensive development projects by showing that, in principle, the development could not succeed. Contributing to the gathering and dissemination of information are the ONR Branch Office personnel at Boston, Chicago, and Pasadena. ONR offices in London and Tokyo provide windows to European and Oriental research. A first-rate science library maintained by ONR is available to all Navy research personnel. The Navy's program can be influenced also by the content of programs supported by other Government agencies whose missions may in part overlap with the Navy's; the Navy research manager therefore meets with scientists of other Government research agencies, both on an ad hoc basis, and on a regular schedule.

One of the more difficult activities confronting the Navy's research manager is interesting the scientific community in pursuing research the manager had judged to be of value in the solution of certain problems. The manager may use seminars or other means of bringing together naval personnel and researchers. His objective is to make both communities conscious of mutual benefits that can result from the awareness by researchers in basic science of problems in the military world as well as the commercial technical community. There are many examples of Navy problems where the Navy's research managers were catalysts for the development of novel technologies or drove existing research in fruitful new directions:

- A requirement of the fleet ballistic program led to the design of a nitropolymer plasticizer—a major contributor to the development of a safe, high-energy, stable solid propellant.
- Marine Corps specification of its requirement for locating enemy troops in dark and remote regions inspired basic electronics researchers to develop personnel sonar systems.
- A long-term basic research effort in fluid lubrication and gas bearings responded to Navy needs by producing the gyroscopes used in inertial navigation systems. These same gas bearings are now common in high-speed tape transports and in flying heads for computer disk memories.
- The application of artificial intelligence techniques to Navy command and control problems was pushed by the desire of fleet commanders for active computer systems which could both alert them to the possibility of impending crisis situations and permit English language man-machine dialogue in circumstances pertinent to the forecasted critical event.

The Navy's research personnel become aware of Navy needs through various channels. Routines have been established for collecting and absorbing documents such as mission statements, planning guides, etc. bearing on research requirements. Attendance at workshops sponsored by the Chief of Naval Operations and the Chief of Naval Material, where matters of Navy needs are addressed, is beneficial. The research managers familiarize themselves with and interact closely with the Navy's operational communities.

The optimum consequence of the Navy's basic research program is, as mentioned above, the introduction of new science or technology into the fleet. The second purpose, then, of the close interaction between research and operation personnel is this function. It has required continuing and personal communication and dialogue between the

two communities. While it has sometimes been difficult to establish the necessary feedback loops, there is a long history of the transfer of naval research to naval operations. Examples include the following:

- Mathematical progress in developing optimal choices under conditions of budgetary and space constraints was picked up by the Polaris program and followed through by research efforts to the point of creating a formalism for the onboard spare parts loading of deployed Polaris submarines.
- Pioneer ONR-supported research in the freezing and thawing of blood led to significant extensions in storage capabilities for this vital material. These techniques made possible the use of frozen blood banks in Vietnam and eventually were utilized by civilian hospitals.
- Computer time-sharing, an innovative concept initiated with Navy and the Defense Advanced Research Projects Agency (DARPA) resources created a worldwide revolution in information-processing methodologies and represented the foundation stone for now-realized Navy and DOD interests in reducing costs and connecting geographically dispersed computational sites.

Finally, contributing to the widest dissemination of the results of the Navy's research program has been the ONR policy of insisting on open publication and wide distribution of reports by contractors. A welcome, not often recognized, byproduct of the Navy's research program has been its contribution to a new generation of scientists; many of the top men in their respective fields today received Navy support during their graduate education and as fledgling independent investigators.

In summary, the Navy research program, coordinated by ONR, clearly goes beyond the funding of research for the sake of research. In short, the program:

- Supports basic research to meet future Navy needs.
- Analyzes present deficiencies and future needs for translation into research goals.
- Establishes a channel whereby useful research results may be introduced into naval operations.
- Provides and maintains the necessary staff and administrative machinery to make the process work.

Organization and Management of Scientific Activities

The Assistant Secretary of the Navy (Research, Engineering, and Systems) is responsible for all matters related to research, development, test, and evaluation within the Department of the Navy and for oceanography, ocean engineering, and closely related matters. His office exercises control on all research, development, test, and evaluation (RDT&E) funds budgeted to the Navy. The programs are administered by the Office of Naval Research, the Naval Material Systems Commands, the Bureau of Medicine and Surgery, and the Marine Corps, and are carried out in Government installations or under contract or grants with private enterprise, universities, and other research institutions.

The Office of Naval Research is charged with planning, initiating, and conducting a broad program of basic and applied research. In addition, it conducts research and exploratory development to augment similar work being done by other elements of the Navy.

The Systems Commands, which report to the Chief of Naval Material, are responsible for technological development, engineering design, and production of ships, planes, weapons, electronics, logistics, and facilities systems. Special research and development projects are headed by project managers who report directly to the Chief of Naval Material and to the various Systems Commanders.

The responsibilities of the Bureau of Medicine and Surgery are aviation medicine, fleet health care, fleet occupational health care, human performance, dental research, submarine and diving medical research, and infectious diseases.

The principal role of the Office of Naval Operations in research and development is to advise the Navy Material Command of the Navy's future needs with regard to ships, aircraft, weapons systems, and related support systems. This Office makes the final decision as to the ultimate production and use of equipment that has resulted from research and development programs. Reporting to the Chief of Naval Operations is the Oceanographer of the Navy, who has the responsibility for coordinating matters of ocean science, ocean engineering, and ocean operations.

The Commandant of the Marine Corps exercises responsibilities for determining and planning for the support needs of the Marine Corps and ensures the USMC RDT&E program is responsive to those needs.

Examples of Basic Research

It is well known that the early history of ONR involved much support of basic research. Not only was there support of individual research projects, entire fields were developed, such as radio astronomy and low temperature physics; techniques were evolved with far-reaching consequences in research and technology, such as nuclear magnetic resonance for chemistry and defect theory in metallurgy; and instrumentation and facilities were developed over many years for use in geophysical research. This Nation's postwar leadership in high-energy nuclear physics would have been impossible without the major efforts of ONR.

This early activity provides a background for discussion of more recent accomplishments. In this inquiry, no attempt was made to cover all areas of Navy research. The Navy is not as extensively involved in basic research as was once the case. The following examples should be considered as selected, representative accomplishments.

Geophysics. In some areas of geophysics, it is possible to state broadly that the Navy is still a strong participant in relatively basic aspects of research. Thus, ONR participated in, and continued to support a significant part of the large-scale experiments in oceanography that have occurred recently and some of which are still going on: MCDE, POLYMODE, NORPAX, INDEX, AND MILE. In the Arctic, likewise, ONR participated in the preparatory phases, logistics, and part of the research support for the major AIDJEX experiment. The Vetlesen Prize in 1975 was awarded Dr. C. L. Pekeris for his work on the tides, supported for many years by ONR.

Astronomy. The Naval Research Laboratory (NRL) has remained active in the areas of radioastronomy, x-ray and ultraviolet astronomy, and solar ultraviolet and x-ray astronomy, under H. Friedman and R. Tousey. Among the credentials attesting to the merit of this work can be cited the award of the Medal of Science to Dr. Friedman and the continued participation by NRL in Skylab and in other space vehicles on a competitive basis. Recent papers from these efforts at NRL that have a significant number of recent citations are: G. R. Carruthers, *Astrophys. J.* Vol. 161L, 1970, p. 81; *Science,* Vol. 177, 1972, p. 788; R. Tousey, *Solar Phys.*, Vol. 33, 1973, p. 265; M. M. Shapiro, *Ann. Rev. Nucl. Sci.*, Vol. 20, 1970, p. 323. Also at NRL, the work of the Karles on molecular and crystal structure has received much recognition. I. L. Karle, *J. Am. Chem. Soc.*, Vol. 92, p. 3755, 1970; *J. Am. Chem. Soc.*, Vol. 94, p. 81, 1972; *Proc. Nat. Acad. Sci., US,* Vol. 70, p. 1836; *Biochemistry,* Vol. 13, p. 2155, 1974.

Physical science. In the physical science areas, Nobel Laureate Dr. C. H. Townes was also awarded the 1977 Earle K. Plyer Prize of the American Physical Society for his work using maser and laser techniques in molecular spectroscopy, notably those in interstellar space. ONR participated in the support of Dr. Townes' recent efforts to explore the millimeter and near infrared wavelengths using maser techniques as well as his earlier pre-Nobel Prize research. Drs. W. Kohn and N. Lang were awarded the 1977 Davisson-Germer Prize of the American Physical Society for their contributions to the understanding of the inhomogeneous interacting electron gas and of its application to electronic phenomena at surfaces. This work was supported in part by ONR. ONR also participated in the atomic clock measurement by Dr. C. O. Alley of the general relativistic time differences produced by aircraft flights. The time difference between two interchangeable sets of macroscopic cesium atomic clocks was measured by direct comparison before and after one set was flown in a radar-tracked naval aircraft in five independent flights. Remote comparison was made using laser pulses. The results confirm Einstein's equivalence principle and constitute the first practical application of his theory of gravitation.

Chemistry. The work on boranes for which W. N. Lipscomb was awarded the Nobel Prize in chemistry was supported in large part by ONR.[1]

Fundamental research. Recent techniques of significance for fundamental research include: Two photon spectroscopy, Doppler-free, extended to the study of general atomic and molecular transitions by use of a nitrogen-pumped dye laser. The narrow line width promises a more precise measurement of the Rydberg constant and also possibly an optical frequency standard.[2]

Mathematics. In the mathematics area, the genesis of the field of sparse matrix analysis by graph theoretical characterization was the work of ONR contractors, S. Porter and later D. Ross. Another example of this type was the thesis of J. A. George on the finite element method. This work is considered to have set the proper questions for further work which has fundamentally changed the way many types of partial differential equations are solved numerically. Still another example is the publication of the book by Y. S. Chow, H. Robbins, and D. Siegmund, "Great Expecta-

[1] "The Boranes and Their Relatives," *Les Prix Nobel,* 1976.

[2] "Hydrogen 1s-2s Isotope Shift and 1s Lamb Shift Measured by Laser Spectroscopy," S. A. Lee, R. Wallenstein, and T. W. Hansch, *Phys. Rev. Letters,* Vol. 35, p. 1262, 1975. Another technique originated under ONR sponsorship is that of phosphorescence microwave double resonance, useful in research on transitions of triplet states in chemistry.

tions: The Theory of Optimal Stopping," (Houghton-Mifflin, 1971), which helped establish a whole new class of statistical tests.

Fundamental fluid mechanics. In fundamental fluid mechanics, supported by ONR, the work of A. Roshko on large-scale structure in turbulent flow is considered significant.[3]

Biomedical. In the biomedical area, the work of Dr. J. Barchas on the role of brain catecholamines in regulation of response to stress won the A. E. Bennet Award of the Society of Biological Psychiatry and has provided analytical techniques for rapid replicate analyses in the course of behavioral experiments. In the area of body temperature regulatory mechanisms, ONR supported the research of Dr. R. Myers, which developed the Myers/Feldberg theory of thermoregulation and elucidated the role of the ratio of calcium to sodium ions in control of the body's thermal set point.[4]

Current and Future Research Emphasis

Although the results of research take many forms, specific categories can be delineated:

- New tangible products, in the sense of new materials or new techniques answering technological needs; for example, new rocket fuels.
- Newly discovered phenomena extending science and providing technological opportunities. Superconductivity is one example.
- New understanding as expressed in the form of models and "thinking tools", e.g., concepts that provide significant new approaches in solving technological problems.

The first two categories need no further discussion, but the last deals with a more subtle phenomenon and often is the basis for successful transition from laboratory bench to factory conveyor belt. An early example is the laboratory demonstration of the need for high-vacuum technology and general cleanliness in producing the exotic refractory metals and alloys which are at the heart of many naval systems. A second example is the development of theories of crystal imperfections which helped physicists conceive and design a number of solid state devices and enabled material scientists to understand and then exploit observed real materials properties as opposed to ideal properties. It is under this category that, in the long run, science makes major payoffs. New philosophies of development and application become evident, frequently involving new talent and new knowledge. (Textbooks and handbooks are important byproducts). Finally, tremendous impetus may be given to one or more branches of science—for example, the impact of cryogenics on physics, chemistry, and biology.

When selecting areas for pursuit of naval research, the manager has options over a broad spectrum of criteria. At one end of this spectrum is support of research at the frontiers of science, whose coupling to application is likely to occur in the future. At the other end is the research which satisfies an immediate need perceived by the development and/or operational communities but which is less likely to be at the leading edge of science. The programs sponsored by ONR usually fall in areas nearer the frontiers of science with the longer term payoff, while those programs managed by the Systems Command and other organizations within the Navy Material Command are usually more closely coupled to direct requirements. Below are presented some selected areas of research that are important from one or both of the above viewpoints. It should be borne in mind that not all disciplines share equally in the range of options at both ends of the research spectrum.

Oceanography

The primary thrust in oceanography is to describe the dynamic water motions in the upper ocean, defining their time and space scales so they may be modeled and predicted for antisubmarine warfare (ASW) purposes. To do this, the physical processes must be understood, including their forcing functions, their dissipation phenomena, and their nonlinear interrelations. Under study are such processes as microstructure, intrusions and internal waves on the thermocline, oceanic fronts between differing water masses, energetic western boundary currents and their degradation via meander-type processes to rings and mesoscale eddies, Pacific sea surface temperature anomalies 1,000 km in diameter that influence all the Northern Hemisphere's climatology, and the control of the surface mixed layer by the flux of heat and momentum across the sea surface, particularly for high-wind regimes. Acoustic transmission studies are carried out simultaneously with extensive environmental measurements of these phenomena to accelerate transition of new understanding of them to the design and improved performance of ASW systems of the Navy. These studies will

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[3]One reference of a series is Garry L. Brown and A. Roshko, "On Density Effects and Large Structure in Turbulent Mixing Layers," *J. Fluid Mech.*, Vol. 64, Part 4, p. 775, 1974. A related piece of work is that of J. T. C. Liu and L. Merkine, reported in *Proc. R. Soc. Lond.* A, Vol. 352, p. 213, 1976.

[4]"An Integrative Model of Monoamine and Ionic Mechanisms in the Hypothalamic Control of Body Temperature," *Temperature Regulation and Drug Addiction*, Editors: J. Lomax, E. Schonbau, and J. Jacob (Karger, Basel, 1975).

determine the limitations on the size of acoustic arrays, the signal processing time for acoustic surveillance systems, and the ocean environmental data required for accurate acoustic predictions.

Other priority areas in the oceanography program are:

- Ground truth verification for satellite remote sensors that can be used to infer ocean conditions below the surface, including infrared and microwave sea surface temperature sensors, precision altimeters for ocean currents, tides and geoidal heights, scatterometer for wave height, synthetic aperture radar for directional wave spectra.
- Development of improved control methods for biological fouling and boring growths that will be compatible with tightening EPA regulations. The emphasis here must be on repellants rather than on today's toxins, such as creosote or organotins. Development of new methods to reduce corrosion by understanding seawater chemistry and the formation of biological slimes that are a precursor to corrosion in seawater. Corrosion and biodeterioration presently are a $200-million-a-year problem to the Navy for pier/piling repairs, added fuel, and dry docking costs.
- Development of the technology for quantitative understanding of low-frequency acoustic propagation in the sea floor, including the use of deep sound sources and ocean bottom seismographs.
- Continuation of refinements of the procedures for analysis of trace organics and inorganics in seawater for possible nonacoustic ASW purposes.
- Development of improved prediction methods for locating sea floor areas where the bathymetry, gravity, or magnetic field must be surveyed in greater detail. Effective geophysical prediction methods will minimize ship time required for ocean surveys.

Arctic Program

The objectives of ONR's Arctic program are: (1) To gain an improved understanding of environmental conditions in the Arctic and of environmental factors that affect Arctic naval operations, (2) to develop new and improved observational techniques for measuring environmental conditions in this area, and (3) to develop improved capabilities for predicting those environmental conditions that have a strong effect on Arctic naval operations. The environmental factors of interest include physical and biological oceanographic conditions under the Arctic ice cap, the acoustic transmission characteristics of these water masses, the ambient noise conditions related to the Arctic ice cap, the dynamic relations between Arctic ice and the overlying atmospheric forces and the underlying ocean forces, atmospheric factors related to weather forecasting and long-range climate predictions. A number of specific field projects are underway or planned for 1977-83 to achieve the above objectives. These include ambient noise model development and field experiments being conducted in the Chukchi Sea and the Beaufort Sea from the Naval Arctic Research Laboratory; Arctic acoustic studies conducted jointly at sea from Alert, Ellesmere Island, and Nord, Greenland, in concert with the Canadians and the Danes; establishment of Manned-Unmanned Environmental Research Stations (MUMMERS) in various parts of the Arctic, used for a variety of environmental measurements; initiation of the Nansen Drift Station across the Eurasian Basin over the mid-Arctic ridge to be conducted in concert with all circumpolar nations; and East Greenland Drift Stream (a multinational investigation of the dynamic land-air-sea-ice processes) within the southerly flowing East Greenland drift stream. ONR participation in most of these projects would include among other things acoustics, remote sensing of sea ice, airborne and sea floor geophysics, atmospheric physics related to improved weather forecasts, and ionospheric research related to long-range communications.

Coastal Geography

The objective of this program is to achieve a basic understanding of the coastal shallow water environment; an understanding of the terrestrial, oceanic, and atmospheric forces which influence this environment has, as a goal, the ability to predict coastal phenomena that affect amphibious and riverine operations.

An example of current research in this area is the study of beach and surf zone processes by investigating wave-breaking mechanisms, longshore currents, nearshore sediment transport, and beach and bottom dynamics. Development of nearshore dynamic models is an important part of the program.

Another current long-range Navy project concerns the design of a computer-based environmental information inventory system for the world's coastal regions. When completed, this system will contain information about data sources, environmental characteristics, and prediction models for the world's coastal regions. The development of various coastal prediction models has been part of this project. The long-range plan is to develop master coastal environmental prediction models for world coastal regions, capable of a high de-

gree of accuracy in predicting complex changes in coastal conditions worldwide for tactical/operational use.

Atmospheric Sciences

The communication problem grows more complex as communication traffic increases and diversifies in response to new equipment and vehicles put into service in the air and on the surface. The ionosphere, a prime regulator of communication conditions, is a dynamic and rapidly fluctuating part of the earth's environment upon which most Navy long-distance communications depend. Both natural and manmade ionospheric disturbances are of critical importance to electromagnetic wave propagation. Atmospheric physics has furthermore been of prime interest because of its importance in weather forecasting.

Accordingly, this research involves the entire atmosphere affecting naval systems and operations, from the marine boundary layer next to the ocean surface to the ionosphere, and its influence on naval communications. The effort is divided into these areas: The lower atmosphere and marine boundary layer concerned with marine fog and aerosol distributions and effects on optical and electromagnetic transmission; midatmosphere cloud physics, upper atmosphere, and stratosphere for the estimation of impact on military operations and the design of high-altitude aerostats for operational uses; and ionospheric plasma dynamics and solar control of the ionosphere and atmosphere for improved prediction of conditions affecting naval communications, navigation, and surveillance systems. Research is being done on measurement techniques and instrumentation, particularly on remote sensing.

Astronomy and Astrophysics

Scientific investigations are made of earth-space environments to determine characteristics of natural backgrounds, effects of energetic radiations on space systems and personnel, and characteristics of manmade disturbances. Data and technology are provided for planning and assessment of improved systems for surveillance, communication, detection, precise time determination and transfer, missile guidance, and navigation. The research effort can be categorized into: Extraterrestrial radio background limits to military systems; far ultraviolet and x-ray background; solar phenomena affecting the earth's ionosphere and satellite environment; near earth energetic particle flux of cosmic rays and effects on sensitive systems; characteristics of manmade disturbances; and supporting instrumentation and vehicle technology.

Mathematical Sciences

Research is encouraged in many fields of mathematics and computer science related to Navy missions. Current research in artificial intelligence seeks to determine how computers can learn and comprehend facts and relationships with the long-range goal of developing humanlike capabilities of adaptation and inference-making.

Fundamental statistical research directed toward analyzing, evaluating, and discriminating stochastic signals related to radar, sonar, and other communications media is underway. Improved system performance will be possible through the development of generalized probability models, better filtering algorithms, and better robust estimation procedures. More sophisticated models are needed to evaluate the environment as well as the stochastic signals generated from that environment.

The ONR plans to establish an acoustics institute in theoretical (mathematical) acoustics which will be closely coupled with experimental and empirical acoustics activity. Work will include methods for calculating wave propagation in a random medium, construction of models of ocean bottom, and general numerical computational techniques appropriate for acoustics problems. The results will have direct application to the design of underwater detection and communication systems and in the design of quieter ships and submarines. Related research in complex command, control, and communications systems will also have direct application to these fundamental Navy missions.

Computational Fluid Dynamics

Computational fluid dynamics is concerned with solving numerically the equations of fluid motion so that useful methodology for the design and optimization of naval ships, aircraft, and weapons can be developed.

Initially, aerodynamic and hydrodynamic flows were emphasized, neglecting the effects of viscosity. Examples include the computation of supersonic flow fields about bodies, a methodology later utilized in both aircraft and re-entry vehicle design studies. Hydrodynamic computations have concentrated on air-sea interface problems, such as hydrofoil performance characteristics. Numerical methods for flows, including the effects of viscosity, are still rather primitive and are restricted to highly idealized fundamental problems.

Problems of transonic flows, viscous flows, unsteady flows, turbulent flows, and ship wave resistance and ship motion in a seaway will be emphasized in the future. Also included will be a

study of the feasibility of developing special purpose computers to reduce drastically the cost of calculating viscous flows.

Physics

Physics as a frontier discipline and, in recent decades, as an applied discipline has so permeated military and civilan technology, that all its manifestations could not be catalogued. The examples given below of current research in the Navy represent a small sample of the diversity of the Navy's physics program.

The potential for lasers to contribute significantly to antishipping-missile defense and to underwater surveillance and communications motivates current efforts in laser physics. Research on the basic aspects of plasmas, ions, atoms, molecules, and crystals is providing the basis for advances in high-energy lasers and for blue/green lasers. This research is also leading to the development and use of lasers for controlled and highly selective production of excited states, a technology with far-reaching economic and military implications.

Research in the area of relativistic electron beams—their generation, their interactions with electromagnetic fields and consequent radiation—offers the potential for generating very high-power, very high-frequency microwave and millimeter wave energy which may in turn provide revolutionary improvements in surveillance and electronic countermeasure systems. This work is part of a general thrust for more effective use of the electromagnetic spectrum.

Superconductive electronics research currently in progress offers promising advantages for future naval communications, surveillance, computer, and electronic warfare systems. The advantages are extremely high speed, large band-width, high sensitivity, low noise, and low device power and loss. A specific example would be analog-to-digital conversion at sampling rates of 1 to 10 Ghz.

Chemistry

The Navy's chemistry program provides research to the Navy and the Marine Corps on aspects of chemical materials and the electrochemical production and storage of energy. Performance criteria for naval chemical materials frequently exceed the capacities of existing materials. New materials must therefore be synthesized and characterization techniques must be developed to predict their performance in a variety of demanding environments such as low (Arctic) as well as high temperatures, high pressure, intense electromagnetic radiation, and highly corrosive chemical environments. The Navy's chemical materials research explores the synthesis of new, high-performance, polymeric materials and especially "inorganic" polymers which contain noncarbon backbones and thus offer new classes of materials totally different from typical carbon-backbone, commercial polymers. Supporting work for this polymer research is also sponsored and includes the development of characterization techniques, such as torsional braid analysis and the synthesis of polymer precursors, such as boron compounds. As already mentioned, the ONR-sponsored research on the synthesis of boron hydrides received attention when Professor William Lipscomb received the 1976 Nobel Prize in chemistry for his contributions to the field. Future directions in the chemical materials area include research on electroactive polymers. It is hoped that this research will lead to nontraditional uses of polymers as piezoelectrics, pyroelectrics, and even conducting materials.

In order to provide a technology base for the development of new batteries for propulsion, communications, and other Navy and Marine Corps needs, ONR sponsors research in electrochemistry related to electrode processes and phenomena associated with high energy density electrochemical systems. These include electrode passivation, dendritic growth of material on electrodes, and the chemistry of nonaqueous electrolyte solutions. A recent product of this research was a new lithium-thionyl chloride battery system with very high density, which is currently under development by the Navy and Air Force for a variety of military uses. This program has special significance because basic electrochemistry research, especially theoretical electrochemistry, is not well supported in the United States.

In support of these broad areas and other general requirements, ONR sponsors chemical research in analysis of the composition and structure of chemical materials and their reaction kinetics and energetics. Special attention is devoted to solids and liquids and their surfaces with an awareness of application areas such as lubrication, corrosion, photo-degradation, chemical light sources, and catalytic processes.

Materials

Almost all developing technologies are paced by materials capabilities. Hence, an important part of the naval research program is directed toward advancing materials technologies. Research is done on metals and alloys, ceramics and inorganic solids, special performance materials, processing of new materials, and deterioration in (and protection from) severe operating environments.

The Navy has played a key role in the development of new metals and alloys. Research continues on titanium, including effort to improve workability by rare earth additions and the analysis of fatigue behavior in beta titanium alloys. Work is also being done on laser welding of high-strength steel, titanium, and aluminum alloys and laser surface treatment of metal alloys.

The Navy is currently expanding its research program on amorphous metals, a new class of materials prepared by very rapid cooling from the vapor or liquid state. The recent availability of amorphous alloy filaments from commercial sources and the discovery of the amorphous state in sputtered metals have created great interest in their potential, but research is needed to explore the mechanical and magnetic properties of these materials.

The Navy has had great success in bringing basic research to bear on technological problems associated with ceramic materials. Emphasis is being given carbon-carbon composites in an attempt to improve the structural reliability of rocket nozzles. Other work deals with: (1) Impact response and erosion mechanisms for missile domes and re-entry materials; (2) sonar ceramics involving processing, reliability, and dielectric stability; and (3) response of optical materials to high-intensity laser light.

Electronics

Future Navy advanced electronic systems require new and improved devices and materials for significantly increased system reliability and performance. Navy-funded research and development complements the existing broad programs supported by U. S. industry. The fields of microwave and millimeter wave electromagnetic technology, optical/IR imaging with solid-state focal plane arrays, extremely dense and fast signal processing technologies, the hardening of electronic devices against hostile physical environments, and the search for new semiconductors operating at higher speeds in unexploited portions of the electromagnetic spectrum are all high-priority research areas.

The natural environment in which future Navy electronic systems will operate is being actively studied. Research on electromagnetic propagation and radiation through the atmosphere and ionosphere with emphasis on investigation of long-range forecasts of solar and magnetospheric disturbances of prime communication links is receiving priority.

As electronic systems have become more sophisticated, they have been difficult to test primarily due to the lack of a uniform scientific base in this area. Modern system theory is now capable of yielding the desired route to a general theoretical formulation for fault analysis, detection, and prediction. Consequently, these latter areas are receiving increased support and emphasis, although they are still underfunded.

Power

The Navy power program is acquiring the scientific knowledge needed to exploit new and improved power and propulsion systems for all naval applications, including ship and aircraft propulsion, rocket and missile propulsion, and energetic explosives for weapons.

Propulsion research emphasizes performance by reducing weight and volume and by improving efficiency without sacrificing reliability. For ship propulsion, the segmented magnet homopolar motor/generator offers potential for all these characteristics at reduced costs. For future naval propulsion systems, the closed-cycle Brayton turbomachine and liquid metal magnetohydrodynamic systems offer further potential improvement.

Research on energetic materials and their sensitivity is addressing future Navy needs for naval munitions and missiles that are very energy dense while maintaining an acceptably low and estimable risk of accidental detonation.

Biomedical

A major research emphasis in the biomedical program deals with the problem encountered by Navy and Marine Corps personnel living and working in stressful environments. High pressure and cold effects associated with the underwater environments are studied with the objective of extending diver performance in military underwater salvage and coastal shelf resources defense. The problem related to deep diving known as the "high pressure neurological syndrome" receives special attention. The syndrome involves a series of symptoms that start with tremors and can develop into convulsions and death depending on the pressure conditions. No satisfactory explanation for this sequence of events has been confirmed scientifically, although most investigators in the field are convinced that the effects are related to the behavior of excitable membranes under pressure.

The effects of electromagnetic fields due to communications equipment and radar are being thoroughly investigated to prevent the restriction of use of naval electronic equipment and at the same time ensure human safety and environmental acceptability.

Research is being done to determine quantitatively the effects of ship motion and impact on crew performance. This work is motivated by an attempt to extend crew performance on advanced ship platforms, particularly the high-speed surface-effects ships.

Behavioral Sciences

Those in a position to make comparisons have characterized American military equipment as significantly better, from the human engineering point of view, than that of other nations. This was due largely to a sustained effort by ONR that led to human performance guidelines for design of systems. The current research program involves a variety of efforts that will produce information and tested techniques for minimizing manpower costs and reducing waste. These efforts range from new and improved forecasting models for estimating the future availability of military manpower with greater precision than now possible to new bases for estimating the likelihood that a given individual will stay in the Navy and be successful if he is recruited. The program also includes innovative approaches to personnel testing and training and continues to make contributions to the improved design of equipment through the application of human engineering principles.

A significant recent contribution is the development of a new model of psychological testing which relates the characteristic measure by the test—a so-called latent trait—to the probability of particular responses to each item in the test. This model is in contrast to current methods which are based on models of the total score on a test. The new theory makes available new tools for creating banks of test items, for constructing parallel tests, and foı conducting computerized adaptive testing.

DEPARTMENT OF THE AIR FORCE

Introduction

The Air Force research program is a vital part of the technology base of the Air Force, the Department of Defense (DOD), and the country. Management actions assure a research program that is scientifically sound, relevant to Air Force needs, and coordinated with other DOD and Federal research efforts. The Air Force research program is managed by the Air Force Office of Scientific Research (AFOSR), an organization under the Air Force Systems Command.

Definition of Research

Research refers to scientific study and experimentation directed toward increasing knowledge and understanding in those fields directly related to explicitly stated long-term national security needs.

Role of Research

Research provides fundamental knowledge for the solution of identified military problems. It also provides part of the base for subsequent exploratory and advanced developments in Defense-related technologies and of new or improved military functional capabilities in such areas as communications, detection, tracking, surveillance, propulsion, mobility, guidance and control, navigation, energy conversion, materials and structures, and personnel support.

The Air Force research program is a continuing program to obtain an understanding of fundamental scientific phenomena required to: (1) Solve the technical problems associated with the development and maintenance of a qualitatively superior Air Force, and (2) develop new knowledge in fields that can lead to higher performance, lower cost, and greater reliability of Air Force weapons systems. The program maintains in-house scientific expertise for immediate availability when needed by the Air Force. The program also provides funding for the operation of the AFOSR contract research program and for reimbursement by AFOSR to all Air Force laboratories for their research programs.

Basic Research Policy

Air Force basic research policy, based on a 1974 memorandum from the Secretary of the Air Force, is:

- Research is a fundamentally important part of the overall Air Force research and development program; the preservation of the quality of that program is of utmost importance.
- Research funding should be protected from undue competition from development and production programs.
- The primary emphasis of Air Force research should be presentation and enhancement of extramural capability to provide insight into the basic science. A secondary goal is to see that students are trained in those scientific disciplines critical to the Air Force.
- The disciplines and programs supported by Air Force research should in general be those of greatest future interest to the Air Force.

- The Air Force research program, while retaining its integrity and independence, should be knowledgeable of and cooperate with the research programs of the other DOD and governmental agencies.

Comparative Analysis and Historical Trends

Prior to 1975, Air Force basic research was concentrated mainly in four organizations: the Air Force Cambridge Research Laboratories (AFCRL), the Aerospace Research Laboratory (ARL), the AFOSR, and the small Frank J. Seiler Research Laboratory (FJSRL) located at the Air Force Academy. AFCRL worked mainly in environmental and electronic sciences; ARL concentrated on mechanics, chemistry, and solid state sciences; and AFOSR managed most of the Air Force extramural research program.

On January 1, 1975, AFOSR became the single manager of Air Force basic research. On June 30, 1975, ARL was abolished. In January 1976, AFCRL was abolished. The electronics laboratories came under the operational control of the Rome Air Development Center. The environmental laboratories were organized as the Air Force Geophysics Laboratory and reoriented toward primarily exploratory development (National Science Foundation [NSF] "applied research"). As part of the realignment of the Air Force research program, the remaining Air Force laboratories, most of which until this time had no basic research responsibility, were required to initiate small research programs. This laboratory readjustment became effective in fiscal year 1977.

The Air Force laboratories devote approximately 7 percent of their manpower to basic research. Of the total Air Force research budget, approximately 30 percent is devoted to in-house research in 11 laboratories. The remaining 70 percent is spent on extramural research, with the majority of these funds managed directly by AFOSR.

One of the reasons for the realignment of the Air Force research program was to reverse the trend of increasing in-house work and decreasing extramural research. The Air Force research budget over a 12-year period is shown below:

FY	In-house	Extramural	Total
		($ Million)	
66	$26.4 (31%)	$58.1	$84.5
67	29.5 (33%)	59.0	88.5
68	34.4 (40%)	52.6	87.0
69	34.6 (38%)	56.2	90.8
70	36.6 (45%)	44.4	81.0
71	39.7 (50%)	40.5	80.2
72	40.8 (50%)	41.0	81.8
73	38.9 (52%)	35.8	74.7
74	41.4 (57%)	31.1	72.5
75	40.8 (55%)	33.4	74.2
76	41.5 (53%)	36.2	77.7
77	23.4 (30%)	54.8	78.2

Basic Research in Agency Laboratories and in Federal Research Centers

Air Force agencies conducting or managing research, their main areas of interest, and their funding in FY 1977 are shown in Table 1. The Air Force research program spends very little money in the Federal Contract Research Centers (FCRC's). The cooperation and interchange between the Air Force research community and the FCRC's are good, as is information exchange, but the funding and management structure of the FCRC/Air Force relationship allows little expenditure of research funds by the FCRC.

Agency Support of Basic Research in Industry

Approximately 8 to 10 percent of the Air Force research budget is contracted to industrial concerns. Actual amounts vary with industry interest in the Air Force program and Air Force interest in the expertise available.

Agency Support of Basic Research in Universities

University-funded research sponsored by the Air Force declined from $42 million in FY 1969 to $25 million in FY 1975. This trend is now being reversed. In FY 1975, approximately 55 percent of Air Force research was conducted in Air Force laboratories. In FY 1977 and for the future, only 30 percent of Air Force research will be conducted in-house. Approximately 10 percent will be conducted in industrial establishments, and 50 percent in colleges and universities. Most Air Force research contracts and grants are managed directly by AFOSR, but Air Force laboratories are encouraged to increase their participation in research with the academic community.

University-Air Force personnel interaction programs already developed will continue in their present mode:

- The major program in which university professors work in Air Force laboratories for 10 weeks during the summer will be maintained at about 55 people. There will be a one-year follow-on minigrant of $10,000, available for

Table 1. Air Force agencies, research interests and funding, FY 1977.

Agency	*Interests*	*FY 77 Funds*
Air Force Office of Scientific Research	Electronics and Solid State Sciences, Physics, Mathematics, Chemistry, Aerospace Sciences, Life Sciences	$45.1
Air Force Armament Laboratory	Mathematics, Mechanics, Energy Conversion	1.4
Rome Air Development Center	Electronics, Physics, Mathematics, Materials	5.8
Air Force Geophysics Laboratory	Environmental Sciences, Chemistry	9.2
Air Force Rocket Propulsion Laboratory	Chemistry, Mechanics, Energy Conversion	.8
Air Force Flight Dynamics Laboratory	Mathematics, Mechanics	2.7
Air Force Materials Laboratory	Chemistry, Materials, Mechanics	4.0
Air Force Avionics Laboratory	Mathematics, Electronics, Materials	1.9
Air Force Aero Propulsion Laboratory	Physics, Chemistry, Mechanics, Energy Conversion	3.1
Air Force Human Resources Laboratory	Human Resources	1.2
Aerospace Medical Division	Life Sciences	1.4
Air Force Weapons Laboratory	Physics, Chemistry, Mathematics, Mechanics, Terrestrial Sciences, Astronomy, and Astrophysics	1.5
	TOTAL	$78.1

about one-half of these visiting professors, if they apply and have acceptable proposals.

- One summer design program per year is planned. This consists of a group of 10 to 15 university faculty members who meet for the summer to address a particular Air Force problem.
- A limited number of faculty members who are experts in a particular area of Air Force need will be hired for one-year periods to conduct research utilizing Air Force laboratory equipment and facilities.

Agency Support of Basic Research by Fields of Science

The approximate distributions of Air Force research funds for fiscal 1966 and 1977 by field of science are shown in Table 2.

Table 2. Distribution of Air Force research funds, FY 1966 and FY 1977.

	FY 1966 ($ Million)	*FY 1977 ($ Million)*
General	$17.3	$8.2
Nuclear physics	3.4	–
Chemistry	5.0	8.1
Mathematics	6.2	7.9
Electronics	8.5	8.4
Materials	2.5	12.4
Mechanics	9.6	11.7
Energy conversion	7.6	5.6
Terrestrial sciences	1.3	1.0
Atmospheric sciences	12.1	5.3
Astronomy and astrophysics	6.3	3.5
Biological and medical sciences	2.2	3.3
Human resources	2.5	2.8

Examples of Basic Research

Because of limited resources, the Air Force research program is not able to address every identified problem. The examples below are some areas on which the program focuses.

High energy laser research. The Air Force provides a substantial amount of basic research support to the high energy laser program. Four Air Force laboratories, the Army, the Navy, and other DOD agencies contribute. Research conducted by the Energy Research and Development Administration (ERDA) and NSF is monitored for contributions to the program. AFOSR manages an extensive research effort in the academic community.

Current areas of interest include chemical lasers, gas dynamic lasers, and electric discharge lasers; pointing and tracking; optical components; propagation; and laser effects. Future work will include electron interaction with excited molecular states; boundary layer effects and mode-media interactions; supersonic, chemically reacting, and radiating flows; and optical materials.

Engine materials research. The Air Force research program on metallurgy of structural ma-

terials devotes a large portion of its effort toward engine materials. The emphasis of this research is on high-temperature materials and phenomena. Air Force laboratories perform research in-house, and AFOSR directs and manages contracts and grants with universities and industry.

The Air Force research program on engine materials is proceeding on a three-pronged approach toward:

- A rational fundamental basis for development of new alloys
- Improvement of existing materials through improved processing
- Understanding and control of design-limiting phenomena.

This program coordinates investigations at Government laboratories, industrial laboratories, universities, and research institutes. The result is expected to be lower cost, higher performance aerospace engines in the future.

Rocket motor combustion instability. Air Force research on solid propellant rocket motors concentrates on solving problems in three areas: Obtaining stable smokeless fuels, accurately predicting and controlling the burn rate, and producing safely handled fuels. Air Force in-house and contracted research is coordinated with several Navy agencies and the National Aeronautics and Space Administration (NASA).

Specific problems being addressed include: Behavior of aluminum during combustion, providing accurate tools for predicting motor instabilities, mechanisms of deflagration-to-detonation transitions (DDT), and stability modeling. Several recent accomplishments in the research community have been passed to service laboratories and industry for further development. When DDT and smoke problems are largely resolved, the program emphasis will shift to higher energy propellants.

Flight simulation training. The Air Force has a significant investment in flight simulation training programs. The effectiveness of flight simulation in terms of transfer of training to airborne situations, however, remains to be explored. Such exploration is necessary to realize the goals of substantial reduction in flying hours, aircraft fuel usage, and flight maintenance and support costs, as well as increased safety and equivalent, if not improved, flying proficiency.

Ultrahigh power microwave generation with relativistic electron beams. This Air Force research program is examining problems in beam-plasma interactions, collective ion acceleration, microwave production, and pulsed power technology. Anticipated payoffs are in the areas of radar, electromagnetic warfare, and communication. The program has produced microwave power levels over 10^9 watts, the highest power levels to date. The goals of the program are to produce sources with high efficiency, power, and repetition rates; and tunability over a given frequency range, and at shorter wave lengths. Plans include investigations into mode locking to produce picosecond microwave pulses; production of microwaves from the interaction of electron beams with plasmas; higher power at submillimeter wave lengths; and further work on a cyclotron maser.

Computer vision. Air Force interest in this field involves the ability to have a sensor examine a scene, have the data transmitted, processed, and abstracted, and finally displayed in a useful fashion to an operational user. The main emphasis of the research is on the mechanisms of scene analysis: preprocessing, segmentation, postprocessing, feature processing, and classification. Other work involves system design, image registration, and parallel processing.

The following list contains a sampling of recent Air Force and Air Force-supported basic research accomplishments:

- The 1974 Nobel Prize in Chemistry was awarded solely to Professor Paul J. Flory of Stanford University for his research on "modes of formation and structure of polymeric substances." Professor Flory's research has been essentially totally supported by AFOSR since 1961.
- Professor Alfred Y. Wong, UCLA, discovered the "caviton" in 1974. The discovery was considered by the American Institute of Physics as one of the three most important advances in plasma physics for that year. Professor Wong's research was supported by AFOSR.
- Mr. Otto Walchner, working from 1964 through 1975 at the Aerospace Research Laboratories, provided definitive measurements of the effect of nose bluntness on the dynamic stability of reentry vehicles. His later work shocked the engineering community by proving that the tricyclic theory could not be applied to bodies with the slightest nose asymmetries.
- Dr. Art Wennerstrom's research in transonic, viscous interactions in turbomachinery, conducted at ARL from 1967 and continuing at AFAPL, led to his design and fabrication of a compressor of very high efficiency. The work continues now at the APL. The Air Force, NASA, and American industry have become interested in this concept and are now beginning a major effort with M.I.T. to determine why the compressor is so efficient.
- Professor George C. Pimentel, University of California, Berkeley, has made several out-

standing scientific contributions while being funded by AFOSR since 1956. Perhaps the best known is his discovery in 1965 of the first successful chemical laser, based on the hydrogen-chlorine explosion. The matrix isolation method was developed in Professor Pimentel's laboratory to permit leisurely infrared spectroscopic studies of highly reactive molecules which would be transient or nonexistent under normal conditions.

- Lt. Robert W. King, of the Terrestrial Sciences Division of the Air Force Geophysics Laboratory, has been analyzing laser ranging observations of the moon to determine more accurately certain geodetic parameters that affect Air Force weapons systems. One of these parameters is the earth's principal geopotential term, GM (G, the Newtonian gravitational constant, and M, the earth mass). All earth gravity models include this term as a factor, and it is a key component of the geodetic and geophysical (G&G) error budgets for Minuteman and the Advanced ICBM. In July 1975, Lt. King reported an improved value for GM to the Defense Mapping Agency (DMA). His analysis provided the most accurate means for determining GM, and the precision of his determination met DMA's projected 1982 ICBM G&G error budget requirements—seven years ahead of schedule.
  Lt. King's analysis has also led to an experimental result of fundamental scientific significance: namely, that the mass responsible for an object's inertia is equivalent to the mass responsible for its gravity field. This is the equivalence principle, the cornerstone of Einstein's theory of relativity. According to several recent theories of gravitation, however, the gravitational and inertial masses of an object are not exactly the same if the gravitational self-energy of the object varies with its position in a gravity field. Such a failure of the equivalence principle could not be detected in a laboratory experiment, but it would cause an anomalous monthly variation of one meter or more in the moon's motion about the earth. Lt. King's five-year analysis of lunar ranging data has shown that there is no such variation to within the accuracy of the range observations, about 15 cm.
- A program begun under the direction of Dr. Paul Carr at the Air Force Cambridge Research Laboratory (AFCRL) in 1968 has provided major contributions to the establishment of a sound scientific base for surface acoustic wave (SAW) technology. The research has involved studies of optimum acoustic materials, wave propagation characteristics, and transducers for converting electromagnetic to acoustic energy. Other research has concentrated on design and fabrication techniques of SAW components, such as delay lines, filters, and resonators. Research is continuing in-house under the direction of the Rome Air Development Center.
- In 1971, the AFCRL Solid State Sciences Laboratory began a program to identify, synthesize, and grow a satisfactory high power laser window material. Halide materials with superior mechanical and optical properties for 10.6 micrometer high energy laser window applications were produced. The halide crystals were grown under ultrapure conditions, hot forged into window configuration, and their mechanical and optical properties determined. A new casting technique was discovered that permits the successful fabrication of such experimental laser windows. Basic research is now essentially complete, and the program is being moved to the Air Force Materials Laboratory for further investigation.

Current and Future Research Emphasis

The most interesting projects involving basic research currently in progress are in high energy lasers, engine materials, rocket motor combustion, flight training simulation, ultrahigh-power microwave generation using relativistic electron beams, and automated sensor data interpretation.

Air Force research funding estimates for the next three years are affected by priorities but also by other factors such as the perceived opportunity for advancement in an area and whether research in a particular area is being done by any other organizations. Funding is greatest for research in materials, mechanics, electronics, chemistry, mathematics, and physics. An intermediate level of funding is carried for energy conversion, atmospheric sciences, astronomy, and astrophysics; and research in biological and medical sciences, human resources, and terrestrial sciences receives the lowest level of funding. This is not to suggest the absolute priority of each area, but an appropriate mix of areas of priority.

Air Force research areas that will receive greater emphasis in the next three years are listed below:

- Aerospace sciences, with emphasis on turbulence and transonic dynamics; heat transfer, turbine blade cooling, and temperature distribution; and environmental effects on composites, and crack and failure mechanisms in metallic and composite structures.

- Chemistry, with emphasis on surface phenomena and interactions between surfaces; high-temperature, high-strength materials; and relationship of processability to morphology and microstructure which control the properties of polymeric materials.
- Electronic and solid state sciences, with emphasis on high-power microwave tube research, low-cost inertial sensing, and structural materials processing.
- Life sciences, with emphasis on human operator performance modeling; environmental protection and toxicological hazards; and simulators for training.
- Mathematical and information sciences, with emphasis on logistics/reliability, applications of microprocessors, and software technology.
- Physics, with emphasis on high energy charged particle beams, high average power tunable lasers, and high power incoherent sources.

Basic research areas that warrant increased emphasis are listed below:

- Greater growth in the turbulence and composite structures programs.
- Research in adhesion to understand the nature of bonding between protective coatings and films and various substrates.
- Dynamics and spectroscopy of new molecular systems for new electronic transition lasers.
- Nondestructive evaluation of both metals and ceramics.
- Human factors in the design of aerospace systems.
- Identification of factors influencing simulator training effectiveness.
- Probability theory and statistics applied to logistics and reliability problems.
- Fault-tolerant systems design.
- Conventional weapons phenomenology.
- Visible and near-IR laser optics in the areas of sources, tunability, and geometry.

Some of the areas warranting emphasis also appear in the list of those areas already targeted for increased emphasis because it is felt that even more resources could be profitably expended there.

Organization and Management of Scientific Activities

The Air Force Office of Scientific Research is the single manager of the Air Force basic research program. Approximately 30 percent of the research is conducted in 11 Air Force laboratories, under the immediate control of the laboratory commander. Sixty percent is conducted by industrial firms and universities through contracts and grants managed directly by AFOSR. The remainder represents contracts managed by the laboratories and support money.

Decisions to initiate and conduct research are based on the importance of the problem to the Air Force, the competence of the investigator, and the budget of the sponsoring organization. Whether the problem will be tackled in-house or outside depends on manpower and expertise available.

There are several mechanisms used to ensure that basic research contributes to the Air Force mission. The validated goals of the Air Force research program are incorporated into the *Research Planning Guide.* These objectives are written by groups comprised of people from the Air Force technology laboratories, Headquarters Air Force Systems Command, and the Air Force research community. AFOSR, with laboratory inputs and coordination, publishes the *Air Force Research Plan* in response to the *Research Planning Guide.* The plan details research efforts directed at achieving the stated objectives.

A yearly *Technology Planning Guide* is published by Air Force Systems Command. This document contains the validated goals of the Air Force exploratory and advanced development programs, the programs to which Air Force laboratories devote more than 90 percent of their resources. The research community contributes a section to the *Technology Planning Guide* on research results ready for transfer to or consideration by development programs.

Prior to FY 1977, most Air Force basic research was concentrated in only a few laboratories and AFOSR. Now, however, each of the 11 laboratories devotes approximately 7 percent of its manpower to basic research. Research at each laboratory, naturally, tends to concentrate on basic studies to support the laboratory's development mission and technology base. With AFOSR as the single manager of Air Force research, assurances can be made that relevant problems are addressed and that results are passed to the appropriate laboratory for consideration in further development planning.

Individual research projects are initiated only if they can be sustained at a critical level of effort determined by the program manager. That is, the program manager determines if there are enough good scientists with enough equipment and support reasonably to assure the problem's solution.

The overall research budget is determined by the Director of Defense Research and Engineering and Air Force headquarters within the congressional constraints of the total Air Force budget. It is at this level that decisions are made on the

amount of resources to devote to basic research in competition with development programs. AFOSR, with the cooperation and coordination of the Air Force laboratories, manages the program at the determined level.

Annual research program reviews with the Office of the Director of Defense Research and Engineering ensure that the Air Force program is coordinated with those of the other services. Meetings with other Government agencies and the scientific community on both a formal and informal basis assure a sound scientific program that is unique to the Air Force.

The optimum situation for Air Force research would be enough good scientists working on every identified problem reasonably to assure its solution. Lack of resources forces the program to focus on certain higher priority problems and ignore others. For instance, of 489 research objectives identified by Air Force Systems Command, the Air Force research plan identified work on only 297, or 61 percent, in FY 1978.

In-house Research

Normally, new in-house research is proposed during the laboratory planning cycle. Each of the 11 Air Force laboratories submits its research plan to AFOSR in the fall. This plan concentrates on the fiscal year following the one about to begin. For instance, plans submitted in autumn 1977 will concentrate on work to be done in FY 1979. Research is proposed in response to the *Research Planning Guide.*

Each research effort is reviewed by at least two higher levels of management twice a year. Progress, problems, the budget, and milestones are reviewed. Decisions on continuation of the effort, relative importance of the work, etc., are based in part on these reviews.

Each laboratory director also has a relatively small amount of money for use in funding small high-risk, high-potential payoff projects. This fund can be used quickly to follow developments occurring outside the normal planning cycle. Projects funded this way are expected to be integrated into the regular laboratory program if they show promise or cancelled before they get too big.

The contract and grant program managed by AFOSR relies primarily on the submission of unsolicited proposals for initiation of new work. Proposals are selected on the basis of originality, significance to science, scientific competence of the investigator, the appropriateness of the proposed research to the Air Force, and the reasonableness of the proposed budget. All AFOSR programs are also reviewed at least twice annually.

Interagency Coordination of Basic Research

Coordination and cooperation are basic to the orderly conduct of research. The most fundamental forms of coordination are the wide reading by, and active participation in scientific societies of, individual project scientists and program managers.

In many cases, several agencies have an interest in conducting or sponsoring research in the same fields of science. When interest is wide enough, or the investment large enough, committees or groups are often formed to direct and coordinate the efforts of the interested parties. Unnecessary duplication can be avoided, results disseminated more rapidly, and assurances given that all relevant problems are being addressed. A few of the many examples of this kind of formal interagency coordination are cited below.

- The Joint Services Research Offices Ad Hoc Working Group addresses problems unique to each service's research mission and focuses on ways to institute and maximize cooperative efforts.
- The DOD/NASA Aircraft Simulation Coordination Group has representatives from the three services, the Federal Aviation Administration (FAA), and NASA. The purpose of the group is to exchange plans and ideas on current research and development activities and to speed dissemination and utilization of research findings.
- The National Academy of Sciences Committee on Geodesy, with members from DOD, the National Oceanic and Atmospheric Administration (NOAA), NASA, and the U.S. Geodetic Survey, provides direction to the academic research community by advertising relevant problems to their respective organizations. The committee also facilitates interagency dissemination of research results.
- The Interagency Materials Group, which coordinates basic research in materials, is sponsored by DOD, the Department of Transportation (DOT), the Department of the Interior (DI), NASA, NSF, and occasionally the National Institutes of Health (NIH). Detailed information on research objectives, program thrusts, and budgetary trends is exchanged to assess anticipated impacts resulting from individual agency actions.

The Air Force research program is conducted both in-house, at all of the Air Force Laboratories, and extramurally in universities, industry, and not-for-profit organizations. It has contributed research results that have benefited the Air Force, with spin-offs that have been utilized by others outside the Air Force. It is currently a healthy, viable program with the expectation of contributing more to the well-being of the Nation's technology base.

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

DARPA'S Mission

The Defense Advanced Research Projects Agency (DARPA) functions as a corporate research and advanced development center for the Department of Defense. It develops long-range, high-payoff technologies which do not fall within specific military services (Army, Navy, and Air Force) programs or which have been assigned by the Secretary of Defense or the Director of Defense Research and Engineering. DARPA has rapid response and a minimum of administrative levels facilitated by the lack of an implicit commitment to production. All research is extramural—either at industrial or academic organizations or at service or other governmental laboratories.

Role of Basic Research

DARPA supports no basic research for the accumulation of abstract knowledge. DARPA does support fundamental research in the 6.1 program to provide a foundation for DARPA's major developmental thrusts.

Examples of Basic Research

Major programs in the past decade that have either been completed or largely transferred to a using agency include:

- The Inter-Disciplinary Laboratories in material sciences, established at 12 universities with core support for the materials community and an emphasis on local management for developing a coordinated interdisciplinary attack on research problems in material sciences, was transferred to the National Science Foundation.
- The ILLIAC IV, a supercomputer for research in parallel array processing, was begun under the 6.1 program. The computer is now operational and housed at the Ames Research Laboratory of the National Aeronautics and Space Administration.
- The ARPANET, a worldwide communications network linking hundreds of computers, to be used for research, remote computation, and distributed computation, was developed in the 6.1 program. It has now become operational and is managed by the Defense Communications Agency.
- A five-year effort in speech understanding by computer was recently completed.
- Work in rare earth alloys of unusual magnetic properties has been transferred to the military services.
- Efforts in unconventional rotating electrical machinery including homopolar motors, superconducting materials, and high current solid brushes are being transferred to the military services for design and further development.

The following continuing programs are just now beginning to pay off:

- A large effort in materials for electro-optical systems including laser windows and mirrors, optical fibers, III-V semiconductors (for a variety of uses), pyroelectric materials for vidicons, etc., supports a number of DARPA sensor programs.
- A ceramic materials program is just now developing test components for production of very-high-temperature, low-cost engine parts for turbines, burners, etc.
- A long-term program in artificial intelligence has developed both theory and technology now being applied to automating militarily useful tasks.

Recent projects still in the experimental stage include:

- A number of advanced memory technology programs aimed at making possible very cheap memories in the 10^{10} to 10^{15} bit range and the software techniques for accessing them.
- The rapid location of buried tunnels and other underground emplacements is of significant military interest, and many location techniques are being tested.

Current and Future Research Emphasis

In the near future, priorities will be divided between material sciences, emphasizing electronic and electro-optical materials and techniques for drastically reducing the cost of finished structural components, and the area of information-processing techniques, emphasizing those that are applicable to the problems of command, control, and communications technology.

Organization and Management of Scientific Activities

At DARPA, the research program is managed in the same way as and by the same people who supervise complementary development programs. This is perhaps more appropriate at DARPA than elsewhere since the developmental programs are often very high risk and at the leading edge of technology. While they may be initiated and terminated in principle as rapidly as developmental projects, in practice the type of work involved often dictates a longer time scale. The apportionment of funds between research and development is done on a yearly basis as authorized by Congress. This assures the overall stability of funding, but there is considerable freedom for allocation among the individual contracts.

DARPA is a small organization and its projects tend to be fewer and larger than those of the military service research offices. Further, DARPA does not have its own procurement organization, and all procurements take place through service agents. This provides additional monitoring and coupling as well as alternative paths to DARPA funding.

DARPA was established in 1958. There have been some major programmatic changes in that time. For instance, initially it was primarily directed toward space research, which has since been taken up by the Air Force and NASA. A large portion of its effort in the early years was toward the defender antiballistic missile program, which was transferred to the Army. This has caused major reorientations in the type of research being sponsored, but not in the methods used.

Because research is handled in the same fashion as development, there are no inherent allocations by contractor type. However, because of the work being done, often 40 percent to 80 percent of the funding goes to universities in a particular project, although industrial firms are playing an ever-increasing role.

In the past, there was a greater willingness to establish large research projects or institutes with a fair degree of internal management freedom. As a result of a number of independent decisions, these efforts have almost entirely vanished, bringing the management of research much more in line with that of development projects.

There is no explicit policy for external review committees, although DARPA participates in a number of Department-wide review and coordination programs such as the Advisory Group on Electron Devices.

There are no explicit regulations or policies that affect DARPA's research program more than any other activity (with the possible exception of the additional paperwork generated by queries and statistical analysis within the Federal research establishment).

Security classification is not a problem since all university research is unclassified.

Useful interagency consultation coordination takes place primarily on a case-by-case basis. Several standing committees also exist with which DARPA cooperates in its particular research areas.

DARPA has served as lead agency in a number of research and developmental projects. Because of the nature of its work, it is much less likely to have occasion to use another lead agency.

There are no restrictions on the dissemination of scientific information resulting from DARPA research.

DARPA has had occasion to support contracts in foreign countries, but these are often the result of joint cooperative programs and intergovernmental agreements. They make use of unique facilities or geography and are usually developmental—not fundamental—research. Cooperative programs with developing countries involving long-term cooperation and on-site emplacement of equipment appear to be suffering more and more from a lack of political stability in those countries, which leads to great uncertainty and very long negotiation times.

DEPARTMENT OF HEALTH, EDUCATION AND WELFARE

ALCOHOL, DRUG ABUSE, AND MENTAL HEALTH ADMINISTRATION

Submitted by Francis N. Waldrop, M. D., Deputy Administrator, ADAMHA

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ALCOHOL, DRUG ABUSE, AND MENTAL HEALTH ADMINISTRATION

ADAMHA'S Mission

The Alcohol, Drug Abuse, and Mental Health Administration (ADAMHA) is the lead Federal agency in the national effort to curtail the problems of alcohol abuse and alcoholism, drug abuse, and mental and emotional illness. Since 1974, when it was given the statutory authority, ADAMHA has administered the Federal programs adopted by Congress to help combat these problems. The programs are carried out by the agency's three Institutes : The National Institute on Alcohol Abuse and Alcoholism (NIAAA), the National Institute on Drug Abuse (NIDA), and the National Institute on Mental Health (NIMH). Though ADAMHA is young as an agency, the theme of many programs it administers dates back to 1947, when NIMH began funding basic and applied research. Both NIAAA and NIDA have their historical roots in NIMH. ADAMHA fulfills its mission through the administration of research, treatment, prevention, and training programs. The research program is implemented primarily through the grants mechanism and encompasses both basic and applied research in the biomedical and behavioral sciences as they pertain to alcoholism, drug abuse, and mental health and illness.

Through its research programs each Institute fulfills its mission by: (1) The development of scientific knowledge and methodology directed toward understanding the factors involved in the problem—for the individual and for society; (2) the application of research principles, methods, and techniques to assess and demonstrate the utility of such knowledge for treatment, prevention, and education; and (3) the development of personnel for research, treatment, and prevention in its areas of responsibility.

Definition of Basic Research

Basic research is scientific study directed toward a fuller understanding of the mechanisms and processes underlying the subject of the research. For NIAAA, the subject is alcoholism, and the definition encompasses its etiology as well as the medical and social consequences of alcoholism and alcohol abuse. For NIDA, the subject is drug abuse, and the definition of basic research encompasses studies that may be chemical, biological, behavioral, or psychosocial in nature. Similarly, for NIMH, the subject of interest is behavior, and the research encompasses biochemical, physiological, social, and psychological processes underlying the behavior observed in mental health and illness. The research in each of the three Institutes makes use of animals as well as human subjects and is conducted in both laboratory and field settings.

Role of Basic Research

Basic research, as defined here, is not goal-oriented. Its focus is the understanding of the problems or processes being investigated. This definition is to be contrasted with that of applied research, where the investigator has the specified goal of using, in a pragmatic manner, knowledge and understanding for the purposes of meeting a recognized need. However, it is important to note that the distinction is somewhat artificial in that each class of research can and has stimulated further research, understanding, and problem resolution in the other. It should be pointed out that a separate basic research program is not maintained, but that both classes of research are supported by the research divisions within each Institute. ADAMHA, through its Institutes, can best meet its responsibilities by continuing to support both types of research based on the criteria of state of knowledge, reasonableness, scientific and technical merit, and relevance to mission. This policy recognizes that basic research can and has contributed significantly to the fund of knowledge necessary to address meaningfully our national public health problems. Continued support of basic research is considered essential to the mission of ADAMHA.

Examples of Basic Research

NIAAA

Prior to the formation of NIAAA in 1972, alcohol-related research was supported through the National Center for Prevention and Control of Alcoholism, which was established within NIMH in 1967. Despite its relatively short history, NIAAA has supported scientists who have made significant contributions to the understanding of the metabolic pathways of alcohol and alcohol-induced pathology. Among these are:

- Lieber, Charles, "Pathogenesis and Treatment of Alcohol-Induced Diseases." This investigator has made two discoveries which have had considerable impact on our understanding of alcohol-related medical problems. In the first instance, it was discovered that alcohol is specifically a hepatotoxin which induces the entire range of alcohol-related liver disease, including fatty liver, alcoholic hepatitis, and cirrhosis. This occurred even though test animals were maintained on an otherwise well-balanced, nutritional diet. The second major contribution by this investigator was the discovery that the ratio of two amino acids (alpha-amino-n-butyric acid and leucine) may serve as a specific blood test to detect chronic alcoholism.
- Chance, Britton, "The Enzyme-Substrate Component of Catalase in Alcoholism." This investigator's research in alcohol metabolism demonstrated that a significant amount of alcohol is metabolized by catalase in addition to alcohol dehydrogenase. The recognition of this nonclassical pathway for alcohol metabolism is important because metabolism by pathways other than alcohol dehydrogenase is found in heavy drinkers and alcoholics. This finding may be basic to understanding the etiology and development of liver pathology.

For FY 1976, 57 percent of NIAAA's extramural grant funds were awarded for basic research in the biomedical area. This included, for instance, 24 projects on studies of the central nervous system for research on such topics as alcohol, serotonin, and sodium fluxes; intracellular effects of ethanol on *in vitro* nerve tissue; ethanol effects on *aplysia* CNS maintained *in vitro;* and alcohol effects on synaptic membrane receptors.

The development of several animal models of ethanol dependence, tolerance, and withdrawal are considered by NIAAA to be significant basic research contributions to the study of alcohol addiction. Among these contributions are:

- Gerhard Freund induced physical dependence in the mouse using an all-liquid diet containing ethanol.
- Dora Goldstein perfected an inhalation technique for induction of dependence in mice.
- John Falk obtained high blood alcohol levels and dependence in rats by the use of a behavioral polydipsic technique.
- David Lester selectively bred high and low alcohol drinking strains of rats.
- Richard Meish used operant conditioning techniques to get rhesus monkeys to self-administer alcohol.
- Walter Pieper achieved physical dependence in infant chimpanzees.
- Edward Majchrowicz, in the NIAAA's intramural research program, has developed an intubation technique which rapidly induces physical dependence on alcohol in the rat.

NIDA

More than 95 percent of NIDA's basic research is extramural and is funded primarily by grants. Since its inception in 1972, NIDA has supported many scientists whose basic research efforts were responsible for the discovery of "endorphins"

and opiate receptors. This knowledge is considered fundamental for elucidating the molecular mechanisms involved in drug addition. Among the major contributors in endorphin research are:

- Goldstein, Avram, "Biochemical Mechanisms in Drug Addiction"
- Simon, Eric, "Effects of Morphine and Analogues on Cell Metabolism"
- Snyder, Solomon H., "Johns Hopkins Drug Abuse Research Center"
- Kosterlitz, Hans and John Hughes, "Narcotic Antagonists: Assessment and Mode of Action"
- Way, Eddy Leong, "Narcotic Tolerance and Physical Dependence Mechanisms."

Other important basic research contributions by NIDA-funded scientists include:

- Ralph Mechoulam's discovery of the active ingredient in marihuana, delta-9-THC.
- Daniel Freedman's work in elucidating the mechanisms of action of hallucinogens.
- Maurice Seevers' development of an animal model for determining the abuse liability of drugs.
- Abraham Wikler's pioneering definition of drug abuse in behavioral terms.
- Gabriel Nahas' description of the effects of THC on DNA, metabolism, and on hormone and immune systems.

Although NIDA's research program is primarily extramural, much important research has been conducted at the Addiction Research Center in Lexington, Kentucky, which conducts the intramural programs of NIDA. Contributions made in research at the Center include:

- Identification of a long-lasting partial agonist of the morphine type. Quite recently, some exciting properties of a new analgesic, buprenorphine, have been identified. These may make it not only an especially useful analgesic but also suggest that it has value for treatment. This agent is a partial agonist of the morphine type with a ceiling effect equivalent to about 20 mg. of morphine. It appears to have a very long duration of action.
- The discovery that naloxone is a pure antagonist in man. Naloxone has been shown to have essentially no pharmacologic activity in man other than antagonizing the actions of morphine and, when it is administered chronically, it does not produce physical dependence.
- Receptor identification. Three separate receptors have been identified that contribute to the actions of narcotic analgesics and related compounds. These three receptors are respectively responsible for the euphorigenic, sedative, and dysphoric and hallucinogenic effects of this general class of drugs.
- Addiction and hypophoria. An hypothesis has been put forth that states that the fundamental pathology of addicts and alcoholics is a defect which results in an increased "need' state and feelings of hypophoria. The feelings of hypophoria may be directly related to the increased "need" state and are partly reactive. These give rise to the impulsivity and egocentricity that characterize much of the addict's pathological social behavior. In this regard, it has been demonstrated that addicts and alcoholics have elevated levels of both testosterone and luteinizing hormones.

NIMH

Research in the extramural program is usually investigator-initiated and thus reflects the state of knowledge and interests of scientists studying behavioral and mental health/illness issues and problems. The following list provides examples of significant projects supported in the past 10 years but cannot reflect the breadth of the extramural program.

- Lynch, Gary, "Psychobiological Studies of Neuronal Plasticity." This work demonstrated that damaged tissue with the central nervous system (hippocampus) can regenerate. The sprouting observed in afferent fibers subsequent to a lesion may account for behavioral plasticity and postulated memory mechanisms.
- Sperry, Roger, "Investigation of Neural Mechanisms in Behavior." This research extended and elaborated the notion of hemispheric specialization and the complementary modes of central processing in the two hemispheres of the brain. This work is considered basic to the possible determination of the cerebral organization necessary for psychological characteristics.
- Grossman, Sebastian, "Role of Subthalamic Mechanisms in Ingestion." Different motivated behaviors—i.e., eating or drinking—were elicited in sated animals by direct injection of different chemicals at the same hypothalamic site. This series of studies, which makes use of both lesions and neurotransmitters to manipulate the nervous system, is basic to the understanding of the central mechanisms that organize ingestive behavior in accordance with physiological requirements.
- Estes, William, "Feedback Processes in Punishment and Reward." The theoretical model resulted from a series of animal and human learning experiments integrated within a common set of constructs, theories, and models which accounted for limited amounts

of data. The demonstration that the informational state of the learner modulates the effectiveness of the reward has practical as well as basic significance.

- Quay, Wilbur, "Circadian Phase Shifts and Mental Health." The results of this and similar studies have established that the mental health of humans can be affected by repeated forced shifts in the timing of circadian rhythms. Knowledge of the role of circadian rhythms in the adaptive process has both practical and basic significance for the understanding of mental health/illness and its relationship to periodic environmental stressors.
- Kintsch, Walter, "Text Comprehension and Memory." This research is concerned with the psychological processes involved in the storage and retrieval of meaningful material in memory. Particularly noteworthy is the finding that "meaning" is stored independently of its linguistic or semantic expression. This research has significance for the understanding of brain-behavior relationships in "higher" functions such as memory.

The NIMH intramural research program conducts research on the causes, diagnoses, and methods of treatment of the mental disorders and on the basic biological and behavioral processes that underlie these disorders. In this program scientists are encouraged to do fundamental research and to attack problems that they believe solvable and that are close to the heart of the mission. Greater emphasis is placed on long-term solutions than on short-term successes, and the laboratories generally have provided the scientific freedom necessary for the pursuit of fundamental issues. This philosophy applies not only to such laboratories as Neurophysiology and Cerebral Metabolism, but extends to the clinical programs such as in the Adult Psychiatry and the Clinical Neuropharmacology Branches. Most of the psychiatrists doing research on patients in this program are at the same time carrying out some research that can be described as basic.

A Selection of Significant Basic Research Projects for the Period 1968-1977

The list that follows includes some of the most significant basic research projects carried out in the intramural program during the past 10 years. It is a partial list and is not meant to be all-inclusive. During the past 10 years this program has produced about 3,000 publications. It would be impractical to list them and virtually impossible to provide a "representative" short list.

Julius Axelrod, Ph.D. The control of catecholamine metabolism.

Julius Axelrod, Ph.D. Comparative biochemistry of the pineal gland.

Floyd E. Bloom, M.D. The fine structure and content of brain monamine-containing nerve fibers.

Edward V. Evarts, M.D. Cerebral control of movement.

Seymour Kaufman, M.D. The conversion of phenylalanine to tyrosine.

Marian W. Kies, Ph.D. Myelin-basic protein—its use in establishing a model for autoimmune pathology.

Melvin L. Kohn, Ph.D. Social psychological correlates of occupational position.

Irwin J. Kopin, M.D. False neurochemical transmitters.

Carl L. Merril, M.D. The effect of small viruses and their nucleic acids on the biochemistry of living organisms.

Mortimer Mishkin, Ph.D. Neural mechanisms in vision.

S. Harvey Mudd, M.D. Homocystinuria: Methionine metabolism in mammals.

Louis Sokoloff, M.D. The (14C) deoxyglucose method for the measurement of local cerebral glucose consumption in the brain.

Ichiji Tasaki, M.D. Analysis of the macromolecular structure of the nerve membrane during excitation.

Marian R. Yarrow, Ph.D. A comparison of the retrospective and prospective methods of studying child development.

Current and Future Research Emphasis

The areas of future interest in basic research are, by the very nature of the need for basic research, difficult to predict. In basic research serendipity often plays as important a role as planning. However, some possible directions based on current state of knowledge and research can be suggested for the next few years.

NIAAA

The current basic research priorities of NIAAA are principally in the biomedical area.

- The central nervous system. Little is known about the mechanism underlying alcohol intoxication. Studies are needed to determine the effects of alcohol on brain cell membranes and neurochemistry. More information is needed on the pharmacokinetics of alcohol. There is the need to develop pharmacological agents that abort or mitigate alcohol intoxication.
- Nutrition and the gastrointestinal tract. Investigations need to be done on alcohol-induced damage to the gastric muscosa, as well as on the mechanism underlying malabsorption of vitamins and other nutrients resulting from chronic and excessive use of alcohol.
- The endocrine system. Alcohol ingestion has

a profound effect on the hormonal control of water and mineral balance. The manner in which alcohol may affect the production and release of hormones is not well understood and needs further explication. In view of the great technical and scientific advances made in endocrine research, it is expected that the support base for endocrine-alcohol research will increase.

These important areas of research are expected to attract increasing attention in the coming years. Of special interest will be the relationship between these biological factors and psychosocial ones.

NIDA

The research programs of NIDA seek to extend our knowledge of the pharmacology, biochemistry, and neurophysiology of abused drugs and the mechanisms involved in drug tolerance, dependence, and addiction. The research program includes social as well as biomedical factors. Research areas of current and future interest include:

- Endorphin research. The discovery of endogenous morphine-like substances (endorphins) in the brain of man and other vertebrates is a major milestone in the efforts to understand the mechanisms of action of narcotic drugs. Endorphins may be involved in the addictive process itself, that is, in the development of tolerance and dependence in opiate (heroin) addicts. "Endorphine deficiency" might be identified as a genetic or acquired trait that predisposes some subjects to become victims of opiate dependence. The clarification of this notion by intensive research efforts should be of significance in developing new treatment modalities or in designing better and more effective prevention strategies for opiate addiction.
- A less obvious but equally exciting possibility is that endorphins may somehow be involved in more general processes that control normal behavior and mental health. Two recent reports demonstrated that endorphins can produce a cataleptic state in animals characterized by a failure to respond to environmental stimuli in a normal, functional manner. The possibility that this induced behavior may be an acceptable model for dysfunctional states (such as schizophrenia) warrants further consideration. To examine this possibility, a research effort by NIDA in collaboration with NIMH and/or other institutes is being explored. The biochemical, enzymatic, neurophysiological, neuropsychological, and neuropharmacological questions raised by the existence of these substances will require continuing exploration.
- Genetic and developmental studies. The genetic, mutagenic, and reproductive effects associated with the use of abused drugs alone or in combination with other drugs and environmental stimuli have been studied on a limited basis. Although there are no unequivocal findings that indicate a high risk of genetic damage associated with abused drugs or with drugs used in treatment, a continued program of investigation is necessary in this important area. There are some indications that abused drugs may cause some problems. Preclinical studies are now underway to clarify previous contradictory results concerning the reproductive effects of marihuana. Some limited studies are being carried out with opiates but it is important to conduct more extensive studies to include other drugs.
- Inhalant abuse. This area of drug use exemplifies the problems associated with drug interactions. Not only are the substances used composed of mixtures, but there are potential interactions with other agents and conditions (e.g., barbiturates, malnutrition). The potential problems in these areas have not been sufficiently investigated and should be given more attention in the future.
- Health consequences of chronic marihuana use. Additional research on the effects of chronic marihuana use will be necessary in light of the fact that 36 million Americans have tried the drug and nearly 15 million use it more or less regularly. While the picture regarding marihuana use is far from complete, it should be emphasized that there is good evidence that its use is by no means harmless. Indeed, there is evidence that many years of use by substantial numbers is required for the full implications of widespread drug use to surface. Furthermore, marihuana is most widely used by adolescents and young adults during critical stages in their personality development and while they are developing intellectual and psychosocial skills. To what extent, if any, chronic intoxication affects development is still unknown.

In light of the above, it seems imperative to carry out large longitudinal epidemiological-biomedical studies on the long-term health consequences of regular marihuana use. Such studies should resolve a number of questions regarding the hormonal, developmental, immunological, cardiovascular-pulmonary, and psychomotor consequences of chronic use of marihuana.

NIMH

The extramural research program of NIMH is multifaceted and broadly based, reflecting the complexity of mental health issues. The examples included in this section, while obviously not indicative of the full range of Institute-supported research, are considered representative of current trends manifesting themselves in research—i.e., a biological orientation that requires the skills and techniques of more than one discipline to integrate bodies of knowledge and interest in basic research that has pragmatic implications. Specific projects of current and special interest which fit these criteria include:

- Harvey, John, "Effects of Central Nervous System Lesions on Drug Actions." This research addresses the study of the biochemical transmitter systems in the brain, how the transmitter substances contribute to the propagation of neural impulses, and how the biochemical systems interact within the brain. The study makes use of behavioral, neurological, pharmacological, electrophysiological, and histological techniques. The understanding of the neural transmission/coding process is considered fundamental to the understanding of central nervous system conditions. An important sideproduct of these studies has been the determination that several drugs that have been used clinically have neurotoxic properties.
- Snyder, Solomon, "Neurochemical Actions of Psychotropic Drugs." Basic to the understanding of the mechanism of action of psychotropic drugs is the understanding of the site of such action: the receptor. This study relies on the techniques of neurochemistry, pharmacology, and histology. Though this research is basic in nature it has resulted in an inexpensive and reliable technique for assaying a psychotherapeutic drug and its active metabolites from blood samples.
- Marler, Peter, "Comparative Study of Vocal Learning." This research has acted to integrate and update much earlier data that focused on the nature-nurture controversy. Using birds as the experimental animal, this investigator formulated a sensory template theory of vocal development by demonstrating, through auditory feedback techniques, that both vocal perception and production were modifiable. Recent evidence suggests that the auditory template hypothesis may be fruitful in the understanding of human speech perception and development.

Current projects of interest within the NIMH intramural program include:

John B. Calhoun, Ph.D. Social organization and population density in rodents.

Giulio L. Cantoni, M.D. Study of the S-Adenosylmethionine synthetase of yeast.

Werner A. Klee, Ph.D. Studies on the biochemical basis of narcotic drug action.

Dennis L. Murphy, M.D. Blood platelets as models for the study of neurotransmitter function.

David M. Neville, Jr., M.D. The role of the cell membrane in cellular organization.

Candace B. Pert, Ph.D. The physiological function of opiate receptors and their endogenous ligands.

Louis Sokoloff, M.D. Studies of regional circulation in the metabolism of the brain.

Basic research areas that merit continuing or additional attention within NIMH in the near future include:

- Basic biological and developmental studies. Research in the brain amine systems appears promising and is basic to understanding the mechanisms of action of potentially therapeutic drugs, and the biorhythmic activity of the brain particularly as it may relate to cyclic illnesses and emotional development. Other biologically oriented areas that merit further attention are the abnormal levels of certain enzymes found in mental patients, behavioral genetics, and the neurological and chemical bases for abnormal psychological effects.
- Early adolescent psychobiology and development. Alarmingly high rates of pregnancy, venereal disease, alcohol and drug abuse, vandalism and personal violence, and depression and suicide in early adolescence point to the need for better information about this critical stage of development. Early adolescence is the phase that encompasses the biological changes of puberty; status change in role definition from child to adolescent; and peer influence on attitudes and behavior. Technological advances in endocrinology and social science methodology now make this area ripe for exploitation. There is a need to do careful simultaneous studies of the endocrine and bodily changes of puberty, along with concomitant emotional and behavioral changes. The need for such research is pointed up by the almost absolute lack of reliable information on early adolescent development. Ages 10-15 are not even included as a separate category in the U.S. vital statistics data; this gap in reported data also contributes significantly to the absence of an epidemiology of mental illness in the early adolescent phase.

Research Priorities

Advance program planning, for both the near and far term, is one of the more important functions in the management of research. This function extends to the method of setting priorities, i.e., whether categories of research are permitted to have the same priority or whether each category has its own discrete priority. Questions about research priorities are difficult and become increasingly difficult as the time span the planning covers increases. The report *Research in the Service of Mental Health,* submitted by the Research Task Force of NIMH after two years of study, aptly concluded that "it would be unwise to attempt to set specific priorities—to say, for example, that research on one type of mental illness has a higher priority than research on another type. Setting priorities of these kinds could be detrimental to the research program, because, once established, they become self-perpetuating. NIMH should handle the problem of priorities by flexible and continuous review of planning." ADAMHA expects to support research broadly within the areas defined by its member Institutes, but the specific subareas must depend upon new advances and developments, and the agency must retain the flexibility to restructure its priorities as necessary to pursue promising research of potential relevance to the mission. Without that flexibility, vital or promising research areas may suffer because of insufficient attention and support. ADAMHA's research effort is broadly based and includes both basic and applied studies. Within each of the three Institutes every effort is made to maintain balanced programs. With this approach it is not a question of what areas are not supported but one of relative balance. One of the determinants of the balance is the state of the art in any given field. Added impetus in one field necessarily results in reducing the effort in other areas. The availability of supplemental or contingency resources to maximize the return from promising research areas without detracting from other programs would be helpful.

Organization and Management of Scientific Activities

Each of the three ADAMHA Institutes supports basic research in both the intramural and extramural programs. The extramural programs of the Institutes are implemented largely through grant support, and procedures for review and management are equivalent.

The majority of basic research is within the grants programs and thus is investigator-initiated. Grant applications are assigned to an Initial Review Group (IRG, peer review). The peer review process subjects each new proposal and competing renewal request for research support to a group evaluative judgment as to its scientific and technical merit. The projects finally recommended for approval are those that demonstrated the highest level of scientific merit. Each Institute also has an Advisory Council which, in turn, reviews the recommendations of the IRG's and makes its own recommendations. All grant applications undergo this dual review process. Only applications that have been recommended for approval by both groups may be considered for funding. Institute staffs make the funding decision on the basis of the priority scores assigned to the applications by the review groups.

Within the intramural research environment, most research is also investigator-initiated. Major program influences on the course of the research are: (1) The establishment of laboratories and sections in specific disciplines or problem areas; (2) the appointment of scientists of known ability to head laboratories and sections; (3) the hiring of individual scientists with high competence and known interests; and (4) the flexible assignment of space, staff, and funds for research. Prior to undertaking the research, the individual scientist discusses the research plan with his colleagues and laboratory chief. Once underway, the research, at several additional stages, is discussed and reviewed at the laboratory level and in research conferences with the division and program directors.

Each Institute has its own management mechanisms which regularly assess the research programs and review progress toward the stated goals. Factors that are taken into account in the review include: (1) Compliance with legislative mandates; (2) state-of-the-art and technical advances; and (3) status of the research grant and contract activities.

These reviews permit the Institutes to monitor progress in meeting the mission goals and in identifying areas where additional basic research support appears necessary. Conferences are sometimes convened to stimulate or advance work in particular areas. Resources are then allocated on the basis of:

- Current commitments to on-going projects
- Readiness of the various scientific fields for rapid advances
- Overall program balance.

Basic research has played and continues to play a salient role in ADAMHA's research programs. However, in recent years, particularly in NIMH, there has been a relative shift toward clinical or applied studies.

NATIONAL INSTITUTES OF HEALTH

The NIH Mission

The National Institutes of Health (NIH) is one of the major participants in the continuing effort to improve the health of the people of the United States. The particular NIH role—and one in which it serves as the lead Federal agency—is to develop and disseminate new biomedical knowledge for the prevention, diagnosis, and treatment of disease. It does this in several ways:

1. By expanding the base of scientific knowledge through basic and applied research in laboratory, clinical, and epidemiological settings;
2. By supporting the training of biomedical scientists to ensure continued excellence in research;
3. By assisting in the development of resources necessary for the research enterprise, such as facilities and equipment;
4. By evaluating the safety and efficacy of new forms of diagnosis, treatment, and prevention through controlled clinical trials and field testing measures;
5. By cooperating with other countries in shared areas of concern in biomedical research, training, and communication; and
6. By fostering the transfer of knowledge from research to health care (when such knowledge has clinical application of known safety and efficacy) through dissemination of scientific and technical information, within the Nation and abroad, in medicine, health, and related fields, and through participation in appropriate efforts to introduce complex procedures into the health care system.

NIH pursues its objectives through its Bureaus, Institutes, and Divisions, most of which are located at the Bethesda, Md., campus. There are 12 Bureaus and Institutes at present. Some are oriented toward specific diseases; others represent broader health concerns. They include:

- National Cancer Institute
- National Heart, Lung, and Blood Institute
- National Institute of General Medical Sciences
- National Institute of Arthritis, Metabolism, and Digestive Diseases
- National Institute of Allergy and Infectious Diseases
- National Institute of Neurological and Communicative Disorders and Stroke
- National Institute of Child Health and Human Development
- National Institute of Dental Research
- National Eye Institute
- National Institute of Environmental Health Sciences (located at Research Triangle Park, North Carolina)
- National Institute on Aging
- National Library of Medicine.

In addition, there are the research and support Divisions that provide resources for all the Institutes in common. They include the Clinical Center, Division of Research Resources, Division of Research Services, Division of Research Grants, Division of Computer Research and Technology, and the Fogarty International Center.

To achieve maximum effectiveness, NIH supports research in a wide range of settings—laboratory and clinic, intramural and extramural—and through a variety of working arrangements—individual and group. In certain instances, NIH supports research abroad at advanced biomedical centers and in developing countries.

Extramural research. Extramural research, both laboratory and clinical, rests on the specialized competence of the Nation's health professional schools, graduate schools, and independent research institutes. This is a strong partnership.

Through support of research in universities, NIH promotes the acquisition of knowledge and the development of applications for raising the level of health. The schools benefit by having faculty members who are directly participating in the advancement of knowledge in their areas of instruction. The specialized competence of individual profitmaking organizations is also drawn on extramurally, under contract, for the performance of many specific tasks.

Intramural research. The intramural facilities of NIH consist of several hundred laboratories and the Clinical Center, a research hospital with 500 beds and support facilities. The organization of NIH—with laboratory and clinical research together on the same site—greatly facilitates the agency's role, encouraging cooperation between laboratory and clinic, free exchange of scientific findings, and the generation of hypotheses. NIH management also benefits from daily contact with persons immersed in biomedical research and in touch with the larger national and international communities of their disciplines and specialties.

Research and program project grants. The ideas and activities of the individual scientific investigator working in his own laboratory or clinical setting are the major energizing factors in both intramural and extramural NIH research. The research project grant is the primary mechanism for support of the non-Federal scientist. In recent years there has been an increase in the numbers of pro-

gram project or center grants awarded. Such grants provide aggregate support to teams of scientists and make it possible to organize, at a medical school or university, combinations of individual and group projects especially designed to optimize efforts on a particular research area or problem.

Definition of Basic Research

The R&D activities carried out by these intramural and extramural organizations are generally conceptualized into three major categories—basic research, applied research, and technological development.

- Basic research is concerned primarily with gaining a fuller knowledge or understanding of the subject under study. It is a long-range quest to augment the underlying conceptual structure in a research area.
- Applied research in both the laboratory and clinical setting is aimed at obtaining specific knowledge that will enable the investigator to judge whether it is feasible to produce a new or improved way—that is, technology—of preventing, diagnosing, or treating a particular malfunction. Applied research cannot take place without a relevant scientific base; it is "targeted" to determine whether, with the current knowledge base, a means can be devised to accomplish a specific practical task.
- Technological development at NIH is primarily concerned with clinical applications and draws on the findings and hypotheses reached in applied research in order to create a specific new or substantially improved approach to meeting a definite preventive or health care need in the community or physician-patient setting.

Although these conceptual distinctions can be made, it must be noted that basic and applied research form a continuum, and a specific research project may be basic from one point of view and applied from another. This fact makes it difficult and in some cases meaningless to classify individual projects as either basic or applied; it is usually more meaningful to speak of research as having basic and applied aspects.

Role of Basic Research

NIH supports basic research to expand knowledge and understanding of the properties of the fundamental life processes and of the ways in which disease and impairment may result from such factors as genetic defects, infection, environmental pollution, unhealthy lifestyle, and the aging process. This understanding is a prerequisite for identifying new possibilities of prevention and intervention. As summarized by the President's Biomedical Research Panel Report, basic or fundamental research in biomedical science provides:

> . . .the science base upon which to build improved technologies for the prevention and cure of diseases. Before there can be intelligently conducted applied research, before there can be demonstrations or clinical trials, or before there can be public dissemination of techniques, there must be enough productive basic research to provide the fundamental science from which these efforts flow.[1]

The Panel concluded that a "vigorous program of fundamental research in all Institutes is essential to the continuing strength of the biomedical research effort."[2]

The goal in an NIH basic research program is to achieve, over time, the general expansion of the base of scientific knowledge across a wide front. The outcome and immediate applicability of any particular basic research project is often uncertain since the scientist deals with such a large element of the unknown; therefore, a broad approach is essential. With opportunities always more numerous than resources, it is possible at any given time only to press those scientific possibilities that are judged most promising. An opportunity is promising when the question posed in the project is of high importance to the needs of an NIH program, when the available technology is adequate to make the scientific area ripe for further exploration, and when the investigator is considered highly competent.

The focus on basic research at NIH can be measured by the dollar support devoted to it in recent years. Basic research has enjoyed considerable increase in support as part of the general increase in the NIH R&D budget from 1957 to 1975 (Figure 1). The dollars for basic research have increased from about $37 million to more than half a billion dollars during this period. The relative proportion of basic research, however, has fluctuated. It increased from around 29 percent in 1957 to a high of 38 percent in the mid-sixties, and then returned to the earlier level—about 28 percent—in 1975.

In addition, inflation has eroded the amount of actual research that can be purchased (Figure 1).

[1] *Report of the President's Biomedical Research Panel*, U.S. Department of Health, Education and Welfare, DHEW Publication No. (OS) 76-500, 1976, p. 5.

[2] Ibid., p. 6.

When support for basic research is adjusted to take account of inflation, the adjusted dollars indicate that basic research support advanced from a level of approximately $275 million in 1965 to around $297.5 million 10 years later, a far less dramatic increase than the current dollar figures suggest.

Most of NIH's basic research is performed in extramural institutions, particularly in universities and colleges (including the Nation's medical schools). While the intramural portion of dollar support has increased comparatively slowly over the years, the dollar amount going to extramural institutions for support of basic research has climbed from about $35 million in 1958 to a 1975 figure of close to $424 million (Figure 2). The proportion of extramural funding as a percent of the total has also increased during this time, from 74 percent to 82 percent. Universities and colleges have continued as the predominant performers of basic research. Others include independent research institutes and operating foundations, federally funded R&D centers, industrial firms, State and local governments, and private individuals.

Basic research will continue to play a critical role in the total R&D effort at NIH by providing the fundamental knowledge base upon which applied research and developmental efforts must build. And NIH will continue to rely on the Nation's academic institutions to play a major partnership role in this continuing effort to improve our understanding of life processes.

Examples of Basic Research

Besides dollars for research support, there is another and more important measure of the role and impact of basic research at NIH. It is found in the scientific advances that have contributed greatly to human health and well-being. A number of examples of basic biomedical research achievements follow. It must be emphasized that this is not a definitive listing of all such contributions. Many other examples could be added, as noted in *NIH Research Advances,* one of NIH's annual publications (first published in 1975), or in Appendix A of the *Report of the President's Biomedical Research Panel.*

Elucidation of Cellular and Molecular Immunologic Actions

The past 10 years have seen major advances in scientific understanding of the immune system. This is particularly true in regard to the activity of certain cells and chemical molecules.

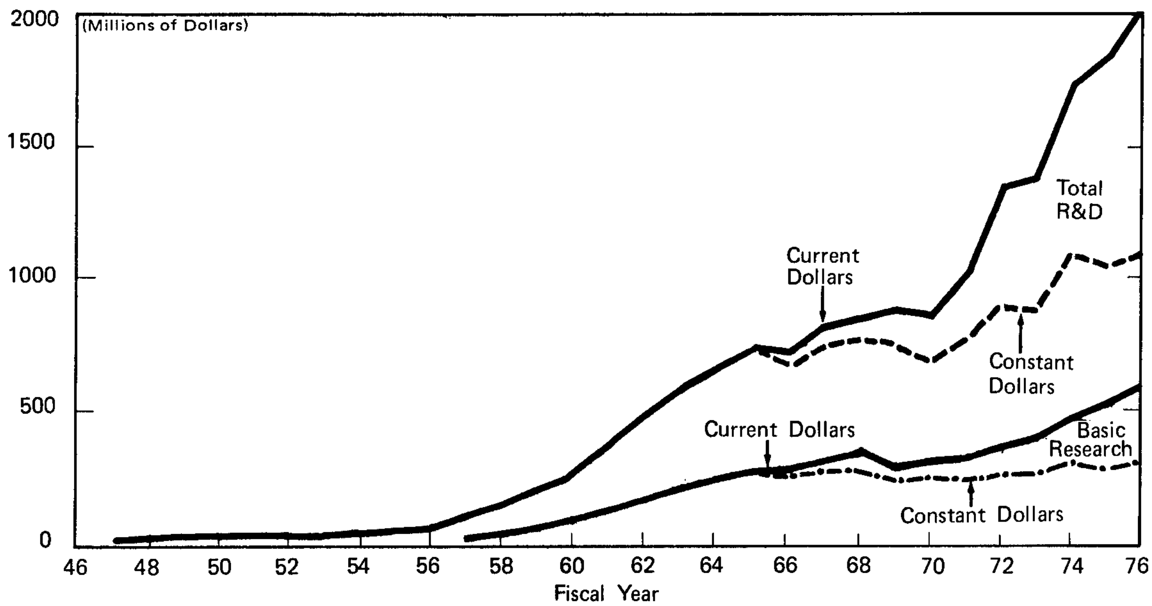
It has been known for some time that, in the immune response, two types of lymphocytes (white blood cells) play major roles. These are the T cells, which depend upon the thymus for their maturation, and the B cells, which are derived from the bone marrow. When a foreign antigen—such as a bacterium, a virus, or an allergen—is introduced into the body, both T and B cells participate in the formation of antibodies. Some types of these blood proteins, generally protective when formed against bacteria, are harmful in certain naturally susceptible individuals when produced in response to an allergenic substance.

Drs. K. and T. Ishizaka, now at Johns Hopkins University, were the first to identify a unique class of antibodies—immunoglobulin E, or IgE—as being specifically responsible for immediate hypersensitivity reactions, or allergies. These grantees of the National Institute of Allergy and Infectious Diseases (NIAID) and others have shown that when IgE fixes to certain cells, contact with allergens such as pollens results in the release of chemical molecules directly responsible for many of the symptoms of allergies—wheezing, runny nose and eyes, etc. Discovery of IgE thus constituted a critical turning point in the field of allergy research. Information arising out of the delineation of IgE function has made it possible to distinguish between those persons with asthma, rhinitis, dermatitis, etc., whose disease is of allergic origin and those whose symptoms are similar but are due to other mechanisms. As a result, proper treatment programs can be instituted.

T cells are also known to play a crucial role in so-called cell-mediated immune responses, such as those involved in graft rejection and in defense against fungal infections. In these immune reactions, a variety of chemical mediators, known as lymphokines, may be released by contact of a specific antigen with previously sensitized T cells. One of the first of these chemicals to be identified is known as macrophage inhibition factor (MIF). This soluble material inhibits the normal movement of macrophages (scavenger cells) to the site of tissue injury. Other factors have since been found to affect the movement of white blood cells such as neutrophils and eosinophils involved in inflammation. Sensitized lymphocytes also produce interferon, important in defense against viral infections, and transfer factor, intimately concerned with cellular immunity. Both of these mediators have been extensively studied for possible clinical usefulness.

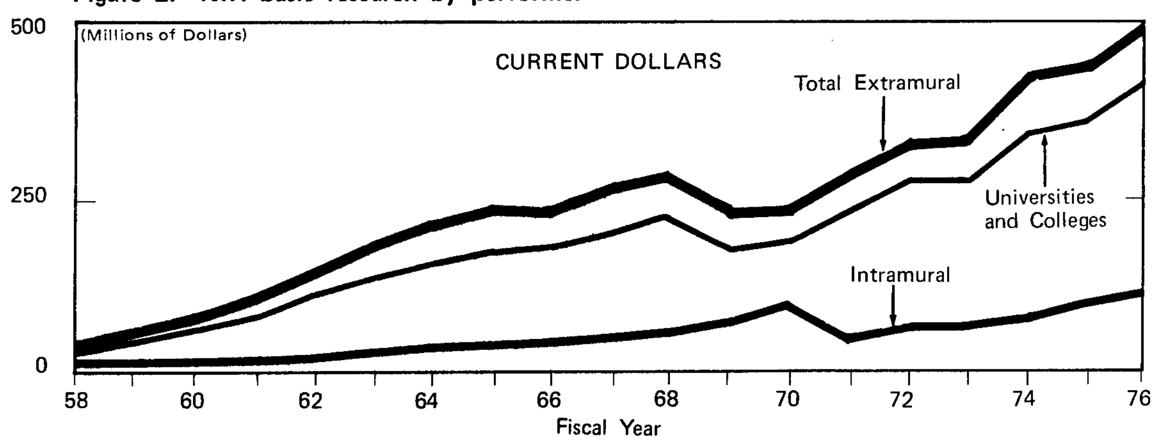
More recently it has been discovered that there is a subpopulation of T cells that actually suppresses the cell-mediated immune response. For example, NIAID grantees at the Mayo Medical School, Rochester, Minn., have shown that patients with

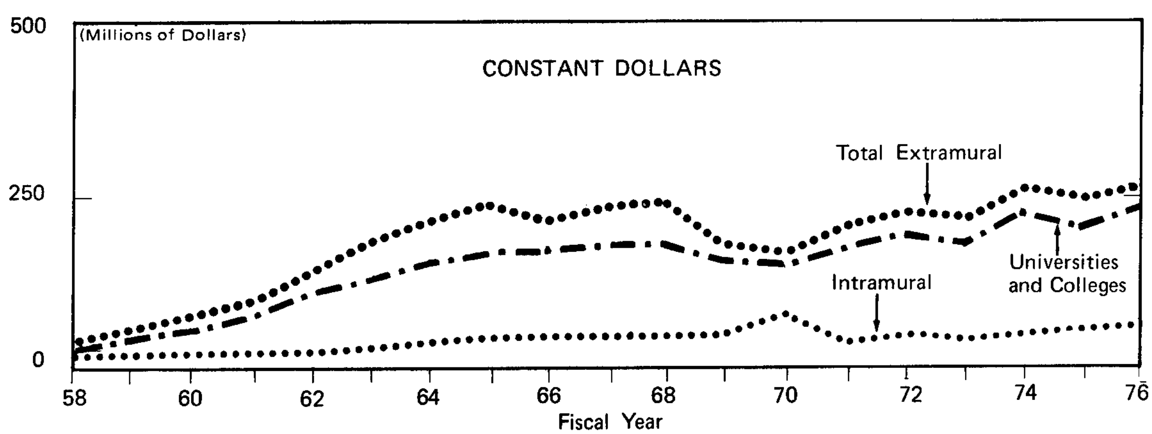
Figure 1. NIH obligations foı total R&D and basic research



Source: NIH

Figure 2. NIH basic research by performer





Source: NIH

widespread fungal infections are unable to mount an immune response because of overactivity of suppressor T cells. If this suppressor function can be regulated in such individuals, it may be possible to cure or at least ameliorate their disease. This strategy of suppressor T-cell regulation may also be used to prevent graft rejection in patients with kidney or other organ transplants.

Research on the phenomenon of graft rejection has resulted in identification of a number of "histocompatibility locus antigens" (HLA antigens) on cell surfaces. NIAID-supported scientists across the country—at Duke University, the University of Wisconsin, the University of California, and elsewhere—have demonstrated that matching HLA antigens of donor and recipient in kidney transplant operations greatly improves the chances of the transplant being successful. Ninety percent of kidneys transplanted between HLA-identical siblings survive two years as compared to less than 50 percent two-year survival rates in grafts between HLA-mismatched siblings.

Genes coding for these inherited HLA antigens were mapped on chromosomes some years ago, but it is only recently that this same chromosomal region (known as the major histocompatibility locus) has been identified as the area in which Ir (immune response) genes can also be found. One of the first scientists to demonstrate genetic influence on the immune response—thus suggesting the existence of such genes—was Dr. Baruj Benacerraf, an NIAID grantee at Harvard. Benacerraf's work with guinea pigs has been repeated and extended by Dr. Hugh McDevitt, Stanford University, and others, including scientists in Dr. William Paul's Laboratory of Immunology, NIAID. Their work with animal models is also being successfully applied to human studies and allergic disease. Further delineation of the structure and function of the products of the many linked genes of the major histocompatibility locus is likely to provide answers not only to the problem of genetic susceptibility to disease but also to the mystery of organ and tissue development during embryonic growth.

Genetic Manipulation and DNA Recombination

It has been known for some 25 or 30 years that genes, the units of hereditary information, are composed of a chainlike chemical called DNA (deoxyribonucleic acid). It has been established for about 20 years that hereditary information is encoded in the DNA molecule by the sequence of the different types of "links" (nucleotide bases) that make up the chain. This nucleotide sequence determines if an organism will be a single-celled bacterium or a more complex multicellular plant or animal, although our understanding of how this is accomplished is still very incomplete. In the past five years, however, a powerful new methodology has been developed by NIH grantees and other researchers for probing into the mechanism by which genes control the development and functioning of living cells. A variety of genes from virtually any organism can be obtained in pure form, and the new methodology of DNA recombination now makes it possible to transfer genes of one kind of organism to another and to construct genetic constitutions that may never before have been seen in nature.

The new techniques have resulted from the discovery of a class of enzymes, the "restriction endonucleases," that can cleave a chain of DNA into specific reproducible segments. Because of the special way in which the chain is cut, the ends are "sticky" and other enzymes (ligases) can interchangeably rejoin the pieces of DNA. By these means, bits of DNA from different species can be joined together, and reintroduced into bacterial cells or into test tube cultures of cells derived from tissues of higher organisms. The modified cells will then grow and multiply, and pass copies of the recombinant DNA on to new cells as they are formed by cell division.

A typical recombinant DNA experiment involves the insertion of genes from a plant or animal into a laboratory strain of bacterium, *Escherichia coli* K-12. This bacterium was established in culture in 1922 and has been more extensively studied than any other organism from a genetic point of view. The genes to be inserted are joined to plasmids, which are small extra strands of DNA that sometimes occur in bacterial cells in addition to their major chromosomes. Plasmids from *E. coli* are extracted, purified, and modified by splicing on new DNA segments derived from some other organism. Then they are reintroduced into living *E. coli* K-12 cells. This process permits the functioning of individual genes from higher organisms to be studied in the much simpler and better understood genetic background of the bacterium. It also makes it possible to do studies on isolated genes themselves, because it provides a convenient way to obtain large quantities of purified genes through "cloning," or growing identical cells in large numbers. Both approaches promise to enhance greatly our understanding of how genes of higher organisms are expressed and regulated.

Another area in which recombinant DNA technology offers hope of important progress is in cloning modified cells for the large-scale production of biological compounds for the treatment and control of disease. For example, it is envisioned that genes for insulin or other hormones could be introduced into *E. coli* so that the bac-

terium would be able to produce the substance itself. Then the modified cells would be grown in large quantities, and the hormone would be extracted and purified for medical use. This method would be an economical way to produce large amounts of pharmaceuticals because *E. coli* is easy to grow, and under appropriate conditions the cells undergo division every 20 minutes. Thus, their number increases logarithmically and one cell can give rise to many billions in a single day.

Other possible applications of recombinant DNA research include studies to increase plant food production by enhancing the efficiency of photosynthesis, and studies to decrease the fertilizer requirements of crops by transferring directly to plants the microbial enzyme systems that perform nitrogen fixation.

It is recognized by recombinant DNA researchers that there may be certain dangers inherent in the technique, dangers not only to laboratory workers but to the environment as well. For this reason molecular biologists established in 1974 a self-imposed moratorium against some kinds of experiments until adequate safety standards could be developed. It was recommended by the National Academy of Sciences that NIH draw up a set of guidelines to govern the conduct of recombinant DNA experiments. The safety standards NIH has now developed prohibit very dangerous experiments, such as transplanting new drug-resistant genes into disease-producing organisms. Furthermore, two kinds of safeguards are prescribed by the guidelines for permitted DNA recombination experiments: Physical containment methods are designed to keep recombinant organisms isolated in the laboratory and to prevent any environmental contamination; biological containment measures are designed to ensure that recombinant organisms are so fragile that they can only survive under special laboratory conditions, so that even if environmental contamination occurs, the organisms will die quickly without spreading.

Role of Membranes

All cells are surrounded by membranes. Membranes are the face a cell shows to the rest of the world and are the site of numerous specific receptors for a wide variety of signals by hormones and other molecules. They represent the principal barrier to the free movement of materials in and out of the cell. Their selectivity, coupled with their electrical insulating properties, permit the storage of both electrical and chemical energy. Membranes also contain the antigens that label the cell and are important in cell-cell interactions and cell recognition in growth, in the development and maintenance of organ structure, as well as in immune response. In addition, cell membranes are a major site of certain classes of enzymes, such as those involved in the synthesis of lipids, including steroids.

Although membranes are essential to the existence of life, not much was known about them until recently. In the past decade, however, there has been a remarkable acceleration in the pace of membrane research and an explosion of advances in the field. Areas of progress include the following:

Membrane composition. Although numerous plasma and cytoplasmic proteins have been purified over the past half-century, it has proven much more difficult to purify membrane proteins. Several successful techniques have recently been devised to purify these proteins. Membrane-associated structural proteins, antigens, receptors, and enzymes have been purified from viruses, bacteria, muscle, and red blood cells, and from mammalian cells grown in tissue culture. A good understanding of the relationship between the type of amino acids in the different segments of a membrane protein and its location in relation to the membrane is being developed.

Fatty structures known as lipids constitute most of the bulk of membranes. Membrane scientists have been steadily improving the techniques of lipid chemistry. Most importantly, novel new methods have made it possible to label lipids selectively on either the inner or outer half of the membrane. It appears that the two halves have different lipid compositions, and scientists are interested in how these differences are established and maintained and why they exist.

Membrane structure. Until recently it was thought that the membrane consisted of a lipid bilayer with a layer of protein on either side. It is now apparent that there are many proteins that span the membrane as well as others that are both in the aqueous phase outside the membrane and partially buried in the membrane lipid. It appears that most membranes are quite fluid and that the membranes essentially float freely in a sea of lipid. In some cells special structures exist to limit the free mobility of proteins. A large battery of highly sophisticated techniques has been developed over the past decade to probe the structure of membranes. Advanced spectroscopic techniques can determine how freely proteins move, how firmly they are associated with surrounding molecules, and how readily the lipids bend, rotate, and flip over to the other layer. Freeze fracture electron microscopy enables researchers to visualize the inside of the membrane and to localize proteins within the lipid matrix. It also permits

them to locate specific cell-cell attachment sites and the release sites for secretory vesicles. Knowledge of membrane composition is now being integrated with the intricate details of membrane structure.

Artificial membranes. Among the remarkable achievements has been the development of techniques to make artificial membranes. Lipid bilayers of known composition can be formed in several ways. Techniques have been devised recently to make bilayers with differing compositions in the outer and inner halves of the bimolecular leaflet. Selected membrane proteins can be incorporated into either or both halves of the leaflet. Chemical, electrical, and spectroscopic measurements can be made on these artificial membranes. One class of artificial membranes, liposomes, can be taken up by some cells and thus allow the introduction of enzymes and pharmacological agents into these cells.

Membrane transport. This entire battery of new techniques has enabled researchers to study the transport of materials across membranes in exquisite detail. It has been possible to investigate the energetics, kinetics, and selectivity of active transport of molecules in living cells. In some cases researchers have been able to purify a specific transport protein and incorporate it into artificial membranes where it will perform as *in vivo.* The study of passive transport of molecules across membranes has also expanded markedly. In addition to physiological transport proteins, several natural and synthetic antibiotics have been found to facilitate ion transport across membranes. Investigators have accumulated extensive knowledge about the molecular details of transport: the shape of the transporting structure, its relationship to the lipid, the energetics of the facilitation of ion flow, the basis for the ionic selectivity, and the kinetics of the flow.

Membrane biogenesis. How membranes are formed in the cell is little understood. The necessary techniques and the appropriate questions are just now being developed. There are some indications that plasma membranes can be formed from vesicles that have broken off from the endoplasmic reticulum and related intracellular membranes. A class of proteins has recently been discovered that can exchange lipid molecules between membranes in different parts of the cell. Whether these lipid transport proteins are involved in membrane synthesis, repair, or some completely unexpected function is not known. Several membrane proteins that span the membrane have been isolated and sequenced. In all these cases the amino-terminal end of the protein sticks out into the extracellular space while the carboxy-terminal end projects into the cytoplasm. Since the amino-terminal end of a peptide is always the part made first on the ribosome, it is hypothesized that the membrane proteins are synthesized directly on a membrane and extruded sequentially through the membrane during synthesis. This area of research is just beginning to be explored.

Slow Viruses and Neurologic Diseases

An important recent accomplishment in biomedical research is recognition of the role played by what are known as "slow" or "latent" viruses in disorders of the central nervous system. These pathogens are viral-type agents that require a long course of action—months or years—before the consequences of the infection become manifest in illness or disturbed function. The first recognition of their delayed action in human disease came from a study of kuru, a severe motor disability resulting from cerebellar degeneration that occurred only among isolated tribes of natives in the highlands of New Guinea.

For his discovery that kuru and another degenerative and dementing disorder of the human nervous system can be caused by transmissible virus-like agents, Dr. D. Carleton Gajdusek of the National Institute of Neurological and Communicative Disorders and Stroke (NINCDS) was awarded the 1976 Nobel Prize in medicine. The Nobel award also recognized Dr. Gajdusek's discovery that the agents causing these two diseases and two other neural disorders in animals are pathogens with properties unlike any known bacteria or viruses and may well represent a completely new biological phenomenon.

In living and working with the natives of New Guinea, Dr. Gajdusek considered that kuru might be a unique form of infection that was transmitted during the ceremonies of ritualistic cannibalism by which the natives honored their dead. When he returned to the United States to head the Laboratory of Slow, Latent, and Temperate Virus Infections at NINCDS, he embarked on an extensive program of inoculating kuru brain material into laboratory animals to discover the causative agent of the disease. There were many unsuccessful inoculations, but finally several chimpanzees developed a disease identical to kuru two or three years after inoculation. Dr. Gajdusek was then able to transmit the kuru agent from these chimpanzees to others, with progressive shortening of the latent period. He has since confirmed this observation many times, and has conclusively proved that the kuru agent is unlike any known organism in man and is a completely unique type of human pathogen.

This work suggested the possibility that many

severe degenerative brain diseases of unknown etiology may be caused by kuru-type slow viruses. One of these disorders now known to be caused by a similar agent is Creutzfeldt-Jakob disease, a progressive presenile dementia, which is more widespread than kuru. The same basic cellular lesions occur in both kuru and Creutzfeldt-Jakob, but the molecular and immunological structure of both viruses remains hidden, eluding attempts to classify them through the usual laboratory techniques.

The viruses involved in kuru and a few other diseases appear to be totally atypical and unconventional. Today only four of these viruses are known; those causing kuru and Creutzfeldt-Jakob disease in man; one causing "scrapie," a fatal illness of sheep and goats; and the causative agent in a disease of mink called transmissible mink encephalopathy.

All these findings have led to new concepts of the etiology of brain degeneration.

Dr. Gajdusek is now coordinating a worldwide collaborative effort to determine the role of kuru-like agents in human disease. What has been discovered thus far may be only the tip of the iceberg; similar slow or latent viruses may be implicated in many of the more common chronic and degenerative diseases of the nervous system.

Protein Structure and Function

Striking advances have been made in the past ten years in understanding the relationship between the structure of enzymes and how they function. Much of this progress has been made through information gained from application of the techniques of amino acid sequencing and x-ray crystallography.

Enzymes are complicated protein molecules made up of strings of amino acids. In order to understand the structure of a particular enzyme, two kinds of information are necessary. The primary structure must be determined; this is the sequence of amino acids as they are joined together to form a polypeptide chain. Also, the secondary and tertiary structures must be known; this is the stable three-dimensional conformation of the molecule as determined by the folding and intertwining of its polypeptide chains; it is unique for each enzyme and maintained by interactive forces within the molecule, such as disulfide bridges and hydrogen bonding between amino acid side chains.

Chemical techniques are used for determining the primary sequence of a polypeptide chain. They generally involve the use of specific enzymes and chemical reagents to split off and identify one amino acid at a time, working from one end of the chain to the other.

The determination of the amino acid sequences of proteins has been proven to be indispensable for biochemists working in a variety of areas. The sequence structure is needed for the ultimate analysis of x-ray data, for studies on molecular evolution, and for identification of active site regions of enzymes (the part of the molecule actually involved in triggering the chemical reaction that takes place), to give but a few examples. The work itself is time consuming and expensive, and requires a high degree of expertise. One of the most distinguished investigators supported by NIH in this field is Dr. Hans Neurath of the University of Washington. Dr. Neurath has spent most of his scientific career analyzing the structure and function of a specific group of proteolytic (protein-digesting) enzymes, the serine proteases. Most recently, his sequence studies of the factors involved in blood coagulation, performed in collaboration with Dr. Carl W. Davie, also of the University of Washington, have shown that many of these factors are proteolytic enzymes that are homologous with each other and with serine proteases in general. Furthermore, the mechanism by which the blood coagulation process operates involves a sequential activation of inactive precursors, similar to the activation of other known serine proteases.

X-ray crystallography is a technique used in determining the three-dimensional structure of an enzyme. It is based on interpretation of the diffraction pattern produced on a photographic plate by an x-ray beam passing through a protein crystal. The characteristics of the diffraction pattern are controlled by the positions of scattering centers—the atoms—within the molecules making up the crystal. Crystals of protein are used so that all the molecules will be lined up the same way; otherwise, each differently oriented molecule would produce a different diffraction pattern, and all these patterns superimposed on a photographic plate would be uninterpretable. Positions of the atoms can be calculated by Fourier analysis of the characteristics of the diffraction pattern, and this information together with the primary sequence defines the complete three-dimensional structure of the enzyme.

An important study in the area was performed by Dr. William N. Lipscomb and his colleagues at Harvard University. They obtained an x-ray structure of carboxypeptidase A, a proteolytic enzyme produced by the pancreas. Their work, together with the primary sequence provided by Dr. Neurath and his collaborators, completely defined the structure of the enzyme. A question remained, however: Did the enzyme have the same shape when bound to its substrate (the substance it acts upon) as it had in a purified state?

To answer the question, additional x-ray structures were obtained of the enzyme complexed with "substrate analogues" (which are biochemically similar to the true substrate but are not rapidly digested by the enzyme). The studies showed that the three-dimensional structure was flexible in the presence of substrate, thus providing clear evidence for the "induced fit" theory of enzyme catalysis. The structure also provided valuable information about the active site of the enzyme and its mechanism of action.

More recently, Dr. Michael G. Rossmann at Purdue University, in his studies on lactate dehydrogenase, has identified a unique type of folding that forms the binding site for a substrate common to all dehydrogenases. Other x-ray structural investigations of this important class of enzymes include the work of Dr. Leonard Banaszak on malate dehydrogenase.

Among the groups of enzymes being studied by crystallographic methods are those involved in regulating metabolic processes. In general, these are very large structures, and progress in this area has been slow. However, Dr. Thomas A. Steitz, at Yale University, has obtained a high-resolution crystal structure for yeast hexokinase. This work is providing insights into the subunit interactions and regulator binding sites of a known regulatory enzyme. Other studies of this type, still in progress, are being carried out by Dr. David S. Eisenberg (University of California, Los Angeles) on glutamine synthetase and Dr. William N. Lipscomb (Harvard University) on aspartyl transcarbamylase.

The crystallographic methodology has been applied to a wide range of macromolecules with some results of considerable medical importance. For example, the structure of one of the macromolecules responsible for the immune response was worked out at NIH by Dr. D. R. Davies and co-workers. The resulting improved knowledge of antibody structure has profoundly changed the immunologist's view of how these macromolecules function in the whole immunogenic mechanism. This may ultimately lead to the engineering of macromolecules that respond to specific contaminants.

Other macromolecule research with more immediate medical payoff is the determination of the structure of sickle hemoglobin by Dr. Warner E. Love and his co-workers at Johns Hopkins University. A simple amino acid substitution in the structure of the hemoglobin macromolecule, which is the main component of blood, causes the blood cells to distort from a flat to a sickle shape. Crystallographic determinations of the subtle shape changes in the hemoglobin are being used to determine why the hemoglobin macromolecules pack in a different arrangement. Knowledge of the conditions that bring about the onset of sickle packing of the hemoglobin has led Dr. William A. Eaton and co-workers at NIH to develop appropriate screening techniques.

Other major advances in the understanding of protein structure and function have come from the application of sophisticated biophysical techniques. Dr. Peter Debrunner at the University of Illinois has been studying the iron reaction center of a cytochrome P450, utilizing primarily the techniques of Mossbauer spectroscopy and electron spin resonance. This protein is believed to be involved in detoxification mechanisms in higher organisms. Dr. Debrunner's studies provide evidence of the state of the iron atom when complexed with oxygen, the bound state of the molecular oxygen, and the possible protein ligands that interact with the iron. Eventually, it is hoped that these studies, together with other approaches, will lead to an understanding of how this protein functions.

Similarly, Dr. Lubert Stryer at Stanford University has applied Raman spectroscopy to the study of the light-induced isomerization of the visual pigment, rhodopsin. These studies should aid in understanding how the visual pigment changes following absorption of light. Studies on a bacterial rhodopsin by Dr. Walter Stoeckenius at the University of California at San Francisco are making significant contributions toward understanding the way organisms respond to light.

A major area of research is on subunit interactions of enzymes that regulate metabolic processes. Dr. Howard K. Schachman, of the University of California at Berkeley, has been studying the nature of the subunit interactions that govern the regulatory role of a bacterial enzyme, aspartate transcarbamylase. Together with Dr. John C. Gerhart, he has found that the enzyme contains two discrete classes of subunits. One class catalyzes the enzymatic reaction, and the other class modifies this reaction through its interaction with small molecular weight activators and inhibitors. Dr. Schachman and his co-workers have been studying the various interactions between subunits, in hybrid species composed of native, chemically modified, and mutant chains, to determine the molecular mechanism of regulation. Similar studies are being carried out on the enzyme from milk that catalyzes the synthesis of lactose. As shown by Dr. Kurt Ebner in 1966-67, this enzyme consists of a regulatory and a catalytic subunit. The mechanism of regulation and the nature of the subunit interactions are being studied by both Dr. Ebner at the University of Kansas and Dr. Keith Brew at the University of Miami.

Nutritional Biochemistry

Recent evidence has emphasized the importance of nutrition at every stage of life. Both prenatal and postnatal nutrition can permanently affect growth and development, behavior, aging, disease, and other life processes. Advances in the science of nutrition offer great promise for improving health, performance, and life expectancy. During the past 10 years, nutritional investigators have made several advances in fundamental scientific knowledge. One of the outstanding accomplishments involves vitamin D.

Better understanding of the metabolism and functions of vitamin D_3 (cholecalciferol) has prompted great interest primarily because of the major significance of the vitamin in a variety of bone diseases. Vitamin D_3 is essential for intestinal absorption of calcium, but we now know that it is not vitamin D itself that is involved in bone metabolism—it must be metabolically converted first in the liver to 25-hydroxyvitamin D_3 and subsequently in the kidney to 1,25-dihydroxyvitamin D_3 before it can function. This active form should really be considered a hormone rather than a vitamin because it is synthesized only in the kidney and acts on a distant target site in intestinal cells, and its production is regulated by a feedback loop involving calcium absorbed in the intestines. Of additional interest is the fact that the metabolic activation of vitamin D_3 is regulated physiologically by the need for calcium or phosphorus. Obviously, disease states can result from a disruption of this metabolic activation.

The major initial finding in vitamin D_3 activation was made by Dr. Hector DeLuca and his collaborators at the University of Wisconsin. They found that cholecalciferol is hydroxylated to 25-hydroxyvitamin D_3 by a specific enzyme in the liver, and must then be converted to the fully active form 1,25-DHCC. The sites of this conversion were the object of intense investigation for a long time. Drs. Fraser and Kodicek in England and Drs. R. J. Midgett, A. Norman, and associates at the University of California, Riverside; Wadsworth Veterans Administration Hospital, Los Angeles; and the UCLA School of Medicine have shown conclusively that the conversion of cholecalciferol to its metabolically active form takes place in the kidney.

In their research, the investigators found that in individuals with hypoparathyroidism or uremia, the stimulation of intestinal calcium absorption is 1,000 times greater when patients are given the active renal metabolite, 1,25-DHCC, than when they are given an equivalent amount of cholecalciferol. This finding suggested that the vitamin D-resistant osteomalacia observed in virtually all chronically uremic patients may result from the diseased kidney's inability to convert cholecalciferol to the metabolically active form.

Following this line of research, Drs. A. Norman, University of California, Riverside; David Baylink, University of Washington, Seattle; and Jenifer Jowsey, Mayo Foundation, have shown that patients with uremic osteodystrophy (bone degeneration due to kidney dysfunction) responded to small quantities of 1,25-DHCC with beneficial changes noted in the plasma electrolytes and in skeletal pathologic findings. Short-term oral administration of 1,25-DHCC to patients with advanced renal failure improved calcium and phosphorous balance, enhanced intestinal calcium absorption, and corrected or improved hypocalcemia (subnormal blood calcium level). Administration of small quantities of the hormone markedly reversed manifestations of secondary hyperparathyroidism (abnormally increased parathyroid activity causing loss of calcium from the bones), and improved the previously prominent osteodystrophy.

The potential of 1,25-DHCC for the treatment of metabolic bone diseases is now being realized, and investigations into this area of nutritional biochemistry are accelerating in an effort to identify its full range of clinical applications.

In related research, Dr. DeLuca at the University of Wisconsin has demonstrated that calcium transport and bone calcium mobilization in anephric rats (without kidneys) can be stimulated by chemical analogs of 1,25-DHCC, which have similar chemical structures but are less expensive and less difficult to prepare. Dr. DeLuca and his associates have found two analogs, 5,6-trans-vitamin D_3 and isotachysterol$_3$, that may be useful in the treatment of hypocalcemia, impaired intestinal calcium transport, osteodystrophy due to kidney dysfunction, and secondary hyperparathyroidism. Of the two, isotachysterol$_3$ can be converted and purified more simply and economically, and therefore holds greater promise for eventual use in cases of renal osteodystrophy.

Neurosciences

The promise of the neurosciences has been stressed by the President's Biomedical Research Panel, which concluded its recent report by saying, in part:

> Perhaps the ultimate challenge to biomedical research, representing the very pinnacle of our understanding of the human organism, lies in neurobiology: how the brain and nervous system develop, how they function in health and disease, how thought occurs, how memory is stored, how we reason, how we are motivated, and how we interact with our physical and so-

cial environment. This Panel commends neurobiology as a compelling long-range interest worthy of national attention.

From the many possible examples of highlights of progress in the past 10 years, a few may be cited:

New and important details of nerve cell structure and interconnections have been revealed by the use of freeze-fracture and scanning electron-microscopic techniques. Calcium ions have been shown to be essential for the release of transmitter agents at nerve-to-nerve or nerve-to-muscle connections. The neurotransmitter, dopamine, has been recognized as a major factor controlling release from the pituitary of prolactin and growth hormone.

In stroke, the blood vessels of the brain have been shown to be especially sensitive to hypertension, but unlike heart vessels, they are not sensitive to elevated levels of cholesterol in the blood. Moreover, the effects of high blood pressure and the development of atherosclerosis in the brain have been shown to be different from those in the heart and general circulation. For epilepsy, the reliable quantification of blood levels of anti-epileptic drugs by clinical laboratories has been achieved.

In virally induced disease of the nervous system in animals, the nature and effects of defective interfering (DI) viral particles have been elucidated, so that we now know that DI particles prevent normal replication and shedding of viruses from host cells and thus either prevent spread of acute infection or produce a chronic degenerative disorder. The study of viral infections and immune responses of host animals has been facilitated by the introduction of a new sensitive, inexpensive procedure called enzyme-linked immunosorbant assay (ELISA). Viral probes and DNA hybridization techniques have also become important tools for studying the mechanisms of viral and immunological diseases and the role of T-lymphocytes in cell-mediated immune responses in the nervous system. These studies of cell-mediated immunity have relevance for multiple sclerosis and amyotrophic lateral sclerosis (ALS).

A great deal of progress has been made possible because of the development of other highly specialized new instruments and techniques. One example is the newer generation of computerized axial tomographic (CAT) brain and body scanners. At the resolution now available, CAT scans of the brain reveal details of anatomical structures and pathological changes (especially demyelination) hitherto available only from invasive techniques. Moreover, the computerized scans can be converted from the original axial or cross-sectional scans of the spinal cord into views in the longitudinal plane, so that the extent of abnormalities and their relationship to other structures are clear. Computerized axial tomography will continue to have an extraordinary impact on diagnostic radiology and clinical management, especially in the neurological and communicative disorders.

Another advance has resulted from the discovery that there is a shortage of dopamine in the brains of patients with Parkinson's disease. This important finding clearly pointed to the possibility of replacement therapy, and led to efforts to treat Parkinson's disease with L-dopa. Improvements in drug therapy have since been made, and progress in the drug treatment of Parkinsonism ranks as one of the major neurological success stories of the past decade.

Receptors for Hormones, Transmitters, and Drugs

Of broad significance have been the identification and isolation of receptors for hormones, transmitters, and drugs and the recognition that many hormones produce effects through a secondary messenger molecule. The findings help explain the ability of the endocrine system to accomplish both specificity and integration.

Research on receptors has played a significant role in improved clinical management of such metabolic diseases as diabetes, through the development of new knowledge about insulin.

Insulin is manufactured in the pancreas, released into the bloodstream, and distributed to cells throughout the body. For insulin to activate a cell, the hormone first binds to specific receptors located on the cell surface. There, receptors serve two major functions: (1) They act to distinguish insulin from other molecules to which they are exposed, and then bind the insulin tightly at the cell surface; (2) the combination of hormone with receptor initiates a signal that activates intracellular processes characteristic of insulin action.

Dr. Jesse Roth and his associates at the National Institute of Arthritis, Metabolism, and Digestive Diseases (NIAMDD) devised methods to measure precisely the binding of insulin to specific receptors on cells. They found that both the number of receptors per unit of cell surface and the tightness with which each receptor binds insulin may undergo changes. These alterations, which were largely unsuspected, influence the effectiveness of a given amount of insulin. In obese persons, and experimentally in obese mice, the number of insulin receptors per cell was found to be subnormal, which accounts for much of the decreased responsiveness to this hormone. Moreover, when obesity is controlled and weight becomes normal, blood glucose and insulin levels

return to normal, the number of insulin receptors on the cell increases, and sensitivity to the effects of insulin becomes normal.

Application of these new procedures has led to the discovery that receptors play a role in at least several other disease states. In uncontrolled diabetic acidosis, part of the resistance to insulin treatment is due to a decrease in the tightness with which receptors bind insulin. Elevated levels of adrenal steroid hormones, whether natural or administered, often cause alterations in the cell receptors which result in derangements of blood glucose and impaired responsiveness to insulin.

The therapeutic implications of this research may extend beyond insulin to all types of hormonal diseases, even including major diseases of other organ systems such as coronary artery disease and several forms of cancer in which hormones play a significant role.

Elucidation of Mechanisms of Enzyme Action Through Study of Enzyme Deficiency Diseases

Since the middle 1960's, Dr. Roscoe Brady and his co-workers in NINCDS have been working to understand the causes of a group of 10 inherited metabolic disorders known as lipid storage diseases or lipidoses. Each of these disorders is characterized by a specific enzyme defect which produces an accumulation of fatty substances called lipids in various parts of the body.

Starting with Gaucher's disease, Dr. Brady and his associates had discovered by 1965 that the accumulation of a lipid called glucocerebroside was due to a deficiency of an enzyme required for the normal disposal of the lipid. Soon after discovering the metabolic defect in Gaucher's disease, Dr. Brady succeeded in developing a diagnostic test for the disease by assaying for the enzyme in small samples of blood. The new test opened a whole new era in genetic counseling; it not only could be used to identify patients and unaffected carriers of the defective gene, but subsequently was adapted to monitor the condition of unborn children at risk, and permitted the antenatal detection of affected fetuses.

Within a year of the discovery of the enzyme deficiency in Gaucher's disease, Dr. Brady and his colleagues showed that another lipid storage disease—Niemann-Pick disease—was caused by a genetic deficiency of the enzyme sphingomyelinase. These discoveries suggested hypotheses for the specific metabolic defects in all of the other lipid storage diseases. The hypotheses were substantiated for Fabry's disease in 1967 and for Tay-Sachs disease in 1969. By 1973, the enzyme deficiencies of the remaining lipid storage diseases had been uncovered as well, and tests had been developed to diagnose affected individuals and identify familial carriers of the genes that cause the diseases.

The hereditary nature of these disorders has made the development of procedures for identifying carriers an important goal. Effective genetic counseling is now possible for all of these disorders because of diagnostic procedures that have been developed. This past year Dr. Brady's group succeeded in synthesizing two clinically important compounds which can be used for the diagnosis of patients and the detection of carriers of Niemann-Pick disease and Krabbe's disease. A third compound has also been developed recently which is useful for the diagnosis of Gaucher's disease. These measurements may be done in conventional hospital chemistry laboratories. Prior to these developments, diagnostic procedures for Krabbe's and Niemann-Pick required the use of radioactive compounds, and they could only be performed in specialized laboratories equipped with radioactive counting facilities.

In 1973, Dr. Brady and his associates launched a revolutionary treatment for Fabry's disease. They were able temporarily to reverse the effects of the metabolic defect in two patients with Fabry's disease by injecting a purified preparation of the missing enzyme into the patients' bodies. This procedure marked the first enzyme replacement therapy for a genetic disorder that has yielded beneficial results. In 1974, injections of the enzyme missing in Gaucher's disease were given to two patients with that disorder and again encouraging results were obtained. These successes suggest that enzyme replacement therapy may offer hope of effective treatment for some of these incurable genetic disorders. Although more work is needed to determine the long-range effects of enzyme replacement in hereditary diseases, the revolutionary demonstration that patients with enzyme deficiency disorders can be benefited by supplementation with purified exogenous enzyme is a landmark of medical achievement.

Another group of hereditary metabolic disorders that has received much attention at NIH is the mucopolysaccharide storage disorders. The work of Dr. Elizabeth Neufeld and her associates in NIAMDD has revolutionized the conceptual and experimental approaches to these metabolic derangements. In each disease, there is a deficiency of one of the many enzymes that work together to break down mucopolysaccharides, chemical substances belonging to the carbohydrate family. Identification of the biochemical defect in Hurler's syndrome and Hunter's syndrome—the two most common of these disorders—has far-reaching

implications for the burgeoning science of enzyme replacement therapy in a variety of genetic diseases.

Dr. Neufeld and her associates had previously shown that patients with Hurler's and Hunter's syndromes—disorders characterized by skeletal deformities, cardiovascular disease, mental retardation, and early death—lack in their cells specific proteins which they named the "Hurler corrective factor" and the "Hunter corrective factor," respectively. The terms derive from studies *in vitro* that revealed that the basic biochemical flaw in each disease could be corrected by replacing the missing protein in cells cultured from the patients.

In subsequent research, the investigative team showed that tissues of Hurler patients have a deficiency of the enzyme a-L-iduronidase, whereas cells of Hunter patients lack the enzyme iduronate sulfatase. The Hurler and Hunter corrective factors were found to have iduronidase and iduronate sulfatase activity, respectively. However, these corrective factors have something more than the ability to function as enzymes: they have special chemical structures that enable them to enter the cells where they will perform their function of breaking down mucopolysaccharides.

A significant clinical application of Dr. Neufeld's research is precise diagnosis—including prenatal diagnosis—of the mucopolysaccharide storage disorders. Another is the identification of carriers of the gene for Hunter's syndrome. Because this disease is transmitted by X-linked inheritance (like hemophilia), the sisters and other female relatives of Hunter patients can pass the disease to their sons. These women can benefit greatly from reliable information about their genetic status.

But clearly the most exciting applications lie ahead—in the hope of effective enzyme replacement for genetic disease. The discovery that enzymes must have specific "address labels" to guide them into the right cells will make the task of preparing enzymes for replacement therapy more challenging but also more likely to succeed.

Tumor Biology and Reverse Transcriptase

In 1970, Drs. David Baltimore of MIT and Howard Temin and Satoshi Mizutani of the University of Wisconsin simultaneously reported the discovery of an enzyme later demonstrated to be the key to the life cycle of the RNA tumor viruses. The enzyme is now believed by some scientists to be a clue to the cancer-causing properties of these viruses.

RNA tumor viruses differ from most other forms of life in the chemical composition of their genes. Most cells have DNA (deoxyribonucleic acid) as their hereditary material, and their genes are expressed by a process involving the transcription of DNA into RNA (ribonucleic acid), which then carries the genetic information to sites of protein synthesis in the cell. This relationship has become known as the "central dogma" of molecular biology. RNA tumor viruses, however, are an exception to the dogma; they have the first part of the process reversed. In these viruses, RNA serves as the hereditary material, and it is transcribed into DNA. Reverse transcriptase, as the newly discovered enzyme became known, is what makes the process possible.

When an RNA tumor virus particle is about to infect a cell, it already contains reverse transcriptase, along with the RNA that makes up the viral genes. It attaches to the surface of the cell and, by a mechanism still not understood, passes its RNA and the reverse transcriptase enzyme inside to the cell cytoplasm. Once inside, the enzyme uses the viral RNA as a template and synthesizes a viral-specific double-stranded circular DNA out of the cell's supply of building block molecules. Then the DNA, which is known as the "provirus," becomes attached and stably integrated into the cell's own DNA. This is thought to be the reason why these viruses are sometimes able to cause cancer. Once integration has occurred, the synthesizing machinery of the cell becomes available to the virus for its own purposes, and several different events may take place. The virus may take control of the cell's transcription and protein synthesis capabilities and direct the production of new viral RNA and proteins for the formation of new infectious viral particles; this is the active reproductive phase of the virus. It may also direct the synthesis of a "transformation protein" which causes certain alterations in the growth properties of the cell; in such a case, a tumor is formed. On the other hand, the integrated viral DNA may remain "silent," i.e., unexpressed, either temporarily or for many generations.

Integrated provirus DNA is replicated just like ordinary cell DNA in the sequence of events preceding cell division. So when an infected cell divides into two daughter cells, viral genes are passed on to the progeny in the same way as other genes of the dividing cell. Virtually all types of normal animal cells have silent virus-like genes, acquired not by infection but by inheritance from their ancestors. The question of where the genes came from and what function they perform is one of the fascinating riddles of modern molecular biology. Some scientists think they may be normal animal genes that happen to resemble viral DNA; others think they are viruses that infected the animal's ancestor and have been maintained in the genome by evolution because they confer

some adaptive advantage.

Occasionally these virus-like genes can be "activated" by chemicals to begin forming complete viral particles, but the cells they inhabit usually do not acquire aberrant growth characteristics as a result.

Conversely, actual cancer-like change in the growth patterns of cells caused by RNA tumor viruses is highly selective: Of the various types of cells they infect, specific viruses "transform" only certain kinds. The fact that reproduction and transformation functions can be separated suggests that they are under the control of different viral genes, and molecular biologists are now working to identify the protein products of various genes to understand better their mechanism of action. This information is vital for an understanding of carcinogenesis, but in addition, it may be useful in clarifying certain questions in developmental biology, because of the specificity between tumor viruses and the cells they are able to transform.

The discovery of reverse transcriptase has been applied in many other ways to research in basic and applied biology:

1. Reverse transcriptase assays have become a sensitive and relatively inexpensive method for measuring the quantity of RNA tumor virus present in cell cultures, animal tissues, or sera known to contain virus.

2. In perhaps the major application of reverse transcriptase to biology, numerous scientists have used the enzyme with RNA of different RNA tumor viruses as a template to make DNA from radio-labelled precursors. The DNA is then used as a molecular probe for investigating the presence of viral-related RNA or DNA molecules in animal and human cells.

3. Purified reverse transcriptase will use many types of single-stranded RNA, in addition to viral RNA, as template. Molecular biologists are using radioactive DNA's synthesized from specific cellular RNA templates to look in various types of cells for RNA similar to the template, and to look for the genes that coded for the RNA.

4. The biochemical and immunological characteristics of reverse transcriptase have been defined so carefully that it can be distinguished readily from the DNA-synthesizing enzymes (DNA polymerases) of uninfected cells. Thus, detection of reverse transcriptase has been used as an indicator of the presence of RNA tumor viruses not visible as whole particles. For example, the discovery of this enzyme in blood cells of some persons with leukemia was the first biochemical evidence that RNA tumor viruses sometimes may be present in humans.

Organization and Management of Scientific Activities

These research contributions result from intramural and extramural systems built upon a particular concern for encouraging and maintaining the highest possible quality in research.

The intramural system of NIH is under the direction of the Deputy Director for Science (assisted by the Assistant Director for Intramural Affairs). Within each of the 10 Institutes that conduct intramural research (the National Institute of General Medical Sciences does not have intramural laboratories), a Scientific Director is responsible for the programs of the Institute. Collectively, the Scientific Directors form a board chaired by the Deputy Director for Science, with the Assistant Director for Intramural Affairs serving as Executive Secretary; this Board constitutes the policymaking and staff promotion review forum for intramural research at NIH.

Within this system intramural research projects are conceived, planned, and implemented by scientists employed at NIH. It is evident that with limited resources available to the in-house research program, only certain research areas can be pursued. These particular areas are defined by the interests and expertise of the senior scientific staff of each Institute. In guiding this staff, the Scientific Director of the Institute (who is responsible for administration and management of the intramural programs) is advised by a Board of Scientific Counselors—an outside group of consultants who meet biannually to review intramural scientists and their research projects and to advise the Scientific Director on allocation of research resources.

Intramural research proposals are normally conceived and proposed by individual research scientists and discussed extensively with Section Heads, Laboratory or Branch Chiefs, and the Scientific Director. Any of these proposals might involve collaborative efforts with other scientists in the same or another Institute at NIH, or with scientists outside NIH. If it appears during this review process that the basic ideas have considerable merit and that appropriate resources can be made available, the NIH intramural scientists will be permitted to begin. On a periodic basis after the project has been initiated, the efforts are reviewed for quality and progress both by scientific peers and administrative superiors and ultimately by the Board of Scientific Counselors.

This research progress review is supplemented by a systematic promotion review process for intramural scientists. Annually, the Deputy Director for Science conducts a promotion review at which each Scientific Director analyzes his entire organi-

zation chart, describing the intramural staffing pattern and identifying those scientists for whom promotions will be sought over the next year's time. These actions include conversions from temporary "staff fellow" appointments to permanent tenure status. A semiannual update of this review is conducted to introduce special actions that may be appropriate for the subsequent six-month period. Such promotions are brought to the assembled Board of Scientific Directors, who conduct an in-depth review of the quality of research, the bibliography, and other contributions of the candidate, not merely with respect to the number of publications, but also the quality of the journals in which they have appeared. The Scientific Directors vote a recommendation to the Deputy Director for Science, who then has ultimate authority to approve or disapprove the proposed promotion action.

A different system obtains in the case of research that is supported extramurally by NIH funds. A different review and management process is used since the external researchers are employees of universities or medical schools, etc. An elaborate peer review system has been established at NIH, comprising Initial Review Groups (e.g., Study Sections), each oriented around a particular scientific area or discipline and composed primarily of outside consultant scientists. These committees usually meet three times annually to consider research grant applications submitted to NIH.

Scientists in an extramural institution make known their research proposals and proposed budgets through a research grant application. Study Sections review these applications, make recommendations as to specific and technical merit, and, for applications that they approve, assign priority scores based on the merit of the proposal. This gives a relative ranking of the quality of a proposal as compared with other proposals submitted to NIH. The proposals are then considered by the Advisory Councils of the Institutes for their relevance to the program mission of each Institute. If the Advisory Councils approve the proposed research, the extramural scientific administrative staff of the Institute recommends to the Institute Director a funding pattern based on available resources and program needs and priorities. The relevance of the proposed research to the Institute mission is an important factor in this regard.

Current and Future Research Emphasis

There are several areas of basic research in biology and medicine which are moving forward rapidly, are generally considered to be very promising, and are attracting the attention of some of the finest minds in biomedical research. Genetics, immunology, virology, and cell biology are such areas which are basic to our understanding of virtually all disease processes, and thus are represented in the research programs of most of the Institutes of NIH. The neurosciences also are receiving more attention in view of the enormous potential that research in this area can contribute to physical and mental well-being.

Genetics. Research in this area includes the further elucidation of the molecular mechanisms that determine the nature of inheritance as well as the processes that may interfere with the normal transmission of information from parent to offspring. Also included are the increasing number of techniques that permit the investigator to regulate and control the genetic process and to map the genes along the chromosomes on which they reside. Many diseases (e.g., diabetes, cancer, cystic fibrosis) are recognized today to have genetic components, and the understanding of such diseases and their treatment are critically dependent upon our increasing knowledge of genetics. The new recombinant DNA technology is expected to provide a powerful experimental approach to many of the challenging questions in this area.

Immunology. Higher organisms have developed elaborate mechanisms—immune responses—by which they react to foreign substances, particularly to foreign proteins and complex sugars. Enormous strides have been made in the past few years in the understanding of these immune processes. Much has been learned about the structures of the antibodies the organism makes when a foreign substance is presented to it. Also, a great deal has been learned about the cells that generate antibodies, the nature of the provocation that initiates the process, and the forces that regulate it. It has been learned that there are immunologic aspects to many diseases other than those that have been considered to be frankly infectious. These include many varieties of arthritis as well as cancer. Immunology has thus grown from a subdivision of microbiology into a basic science in its own right. There is every prospect for continued success in attempts to understand better the immunologic process, upon which depends not only the understanding of disease but also, in many instances, the treatment and prevention of disease.

Virology. This is the study of the smallest, and in some regards, the simplest forms of life. Viruses characteristically are incapable of independent survival and live as parasites in the cells of higher animals or in bacteria. Because of the rapid developments in chemistry, cytology, immunology, and

genetics, much more progress can be made in understanding and exploring the nature of virus particles. They can be seen, cultured, and purified. Their performances can be studied by a wide variety of techniques. Viruses have been linked to the cancer process and also to a variety of presently untreatable degenerative diseases of the central nervous system. These facts alone would demand a high level of endeavor in this important field. In addition, however, because of their relative simplicity of structure and because of the fact that they contain relatively few constituents, they provide an extraordinarily useful model for the study of biological processes in more complex cells which at this time defy analysis.

Cell biology. In the past 20 years there has been considerable progress in identifying many of the minute structures of cells, which are in turn the units making up all living organisms. There is the beginning of an understanding about how the several parts of the cell operate and how they relate to each other. The nature of the cell membrane and of the process whereby substances pass in and out of the cell across this membrane are subjects of intensive and profitable study. The operation of the structures of the cell—the mitochondrion, the microsome, the lysosome, the endoplasmic reticulum, the microtubule, etc.— is an area of most intense and exciting study. It is becoming possible today to identify the abnormalities of these very small structures within the cell and to associate such abnormalities with disease processes in the animal as a whole. A more complete understanding of the organization of the cell, its constituents, and the regulatory events involved in its functions is of paramount importance to the continuing development of biomedical science. Such understanding will inevitably contribute to knowledge of the biochemical bases of many diseases and their possible correction through such promising approaches as enzyme replacement therapy or gene modification.

Neurosciences. The spectrum of basic research encompassed by this category is very broad, ranging from cell culture experiments on isolated neural tissue, and investigations on the anatomical and functional bases for memory, learning, coordination, and higher mental processes, to social science studies in man. From these is expected to emerge a fuller understanding of the development of normal and abnormal perception and behavior. Such advances will contribute to better ways of avoiding neurological impairments and of correcting those that do occur.

Postscript

The gratifying advances of the past and the exciting potential of the future do not, of course, imply that the difficult and challenging task of basic biomedical research is nearing its completion. Future success in unlocking the mysteries of disease clearly depends upon continuing investment in research to further understanding of underlying biological mechanisms.

The question that is often posed in the debate over investments in biomedical research at NIH is what dollar levels should be devoted to basic research in the total R&D effort or what should be the relative emphasis on basic research as compared to applied research or development. Such a general question cannot be answered in the abstract. A clear differentiation between basic and applied research is sometimes not possible, and investments must be made in ways that will take maximum advantage of available opportunities, given the state of the field of research at the time. Promising clinical applications must be pursued, but the waste of resources that results from premature emphasis on targeted work must be guarded against in research areas where the necessary knowledge infrastructure has yet to be adequately developed. Specific investment decisions for both basic and applied biomedical research at NIH are a function of several conditions: (1) the "ripeness" of science advancements; (2) the availability of specific ideas, applications, and proposals from the scientific community; and (3) the judgments that have been made regarding priorities of particular disease areas, and the relevance and potential contributions of the research to such areas. All of these considerations need to enter into judgments and decisions for support of research, and both the scientific community and the public must be engaged—in their appropriate roles—in the decisionmaking process. It is out of such deliberations by all concerned parties that research at NIH is continuously shaped.

NATIONAL INSTITUTE OF EDUCATION

The National Institute of Education (NIE) was established by Congress in August 1972 under the General Education Provisions Act of 1972 (Public Law 92-318). It took over most of the research functions of the Office of Education.

NIE's Mission

The general mission of NIE is set forth in its legislation, which established NIE to carry out the following policies:

Sec. 405 (a) (1) The Congress hereby declares it to be the policy of the United States to provide to every person an equal opportunity to receive an education of high quality regardless of his race, color, religion, sex, national origin, or social class. Although the American educational system has pursued this objective, it has not yet attained that objective. Inequalities of opportunity to receive high quality education remain pronounced. To achieve quality will require far more dependable knowledge about the processes of learning and education than now exists or can be expected from present research and experimentation in this field. While the direction of the education system remains primarily the responsibility of State and local governments, the Federal Government has a clear responsibility to provide leadership in the conduct and support of scientific inquiry into the educational process.

(2) The Congress further declares it to be the policy of the United States to—

(i) help to solve or to alleviate the problems of, and promote the reform and renewal of American education;

(ii) advance the practice of education, as an art, science, and profession;

(iii) strengthen the scientific and technological foundations of education; and

(iv) build an effective educational research and development system.

This mission is made more explicit in NIE's reauthorization for the three-year period FY 1977-79.

(2) The Institute shall, in accordance with the provisions of this section, seek to improve education in the United States through concentrating the resources of the Institute on the following priority research and development needs—

(A) improvement in student achievement in the basic educational skills, including reading and mathematics;

(B) overcoming problems of finance, productivity, and management in educational institutions;

(C) improving the ability of schools to meet their responsibilities to provide equal educational opportunities for students of limited English-speaking ability, women, and students who are socially, economically, or educationally disadvantaged;

(D) preparation of youths and adults for entering and progessing in careers; and

(E) improved dissemination of the results of, and knowledge gained from, educational research and development, including assistance to educational agencies and institutions in the application of such results and knowledge. (General Education Provisions Act, as amended.)

Definition of Basic Research

NIE's definition of basic research relevant to education is contained in the following policy adopted September 16, 1977, by the National Council on Educational Research:

"To ensure that fundamental research is a major part of the National Institute of Education's plans for addressing the educational needs identified in its statutory mandate, the Institute shall develop its programs in accord with the following guidelines:

I. DEFINITION

Fundamental research in education is disciplined inquiry whose purpose is to understand why and how education takes place. In fundamental research, the investigator is concerned primarily with gaining a fuller knowledge or understanding of the subject under study.

II. ALLOCATION OF FUNDS

A. At least 20% of the Institute's funds shall be used to support fundamental research relevant to education by FY 1979, and by FY 1985 this shall have increased to at least 30%.

B. An important part of NIE support for fundamental research shall be through grants for projects conducted by individual investigators or small groups of investigators.

III. RESEARCH COMMUNITY INVOLVEMENT

A. The major purpose of research supported under this policy shall be to extend the knowledge gained through previous or current educational research or to explore areas where knowledge is lacking and research is needed. Since those who are most familiar with such areas of research are investigators in the field, the Institute shall, to the maximum extent possible, rely upon their assistance in identifying research needs and research to be supported. This assistance should include, but not be limited to, submission of unsolicited proposals, participation in developing guidelines, and re-

view of proposals by groups of highly capable investigators (with multidisciplinary and cross-disciplinary membership), including investigators close to educational practice.

B. As part of the continuing external review of NIE, the scholarly quality and balance of its fundamental research programs shall be evaluated by outside investigators.

C The Director shall seek to work with all major research associations and organizations whose members may be engaged in fundamental research related to education, to accumulate knowledge about such research and to coordinate the Institute's programs with such research.

IV. COORDINATION
The Director shall seek through the Federal Council on Educational Research and Development and other means to coordinate fundamental research relevant to education supported by Federal agencies, to identify areas of fundamental research which should have greater support by NIE or another Federal agency, and to stimulate fundamental research in such areas.

V. USE OF RESEARCH RESULTS
In concert with the Institute's support for fundamental research work, and the Institute's efforts to involve the research community in this work and to coordinate its work with other agencies, NIE shall seek to report effectively to researchers, educators and educational policymakers the results of fundamental research, and to help them utilize such results in formulating research plans, educational programs and educational policies.

VI. STAFF RESPONSIBILITY FOR FUNDAMENTAL RESEARCH
Because the NIE staff is essential to the implementation of this policy and the support by NIE of high quality research, the Director shall insure that within NIE there is a substantial number and proportion of staff members who are very knowledgeable about fundamental research, have ready access to the research community, and are respected by its members. These staff members shall be consistently involved in decisions about the overall NIE programs and in the management of fundamental research programs.

VII. REPORTS
Initial plans for implementation of this policy shall be conveyed within 60 days, including resource allocations and management strategies. Similarly, by January 1, 1978, the Director shall present to the Council for its concurrence a general plan for implementation of this policy through 1985.

The Director shall include in each annual report to the Council a review of the Institute's fundamental research work and efforts to improve it, and shall present to the Council as part of the budget planning process an analysis of options for support of fundamental research under this policy, including targets for the amount and proportion of funds which might be thus allocated."

Role of Basic Research

From the time of its creation in 1972, NIE has regarded basic research as the essential means of carrying out its legislative charge to strengthen the scientific foundations of education and as an important element in the pursuit of its other objectives. Concern about the best means of carrying out this part of the NIE mission led the Director of NIE, at the suggestion of the National Council on Educational Research, to commission a study by the National Academy of Sciences in 1976. This study led to a report, *Fundamental Research and The Process of Education.* The report formed the basis for discussions involving the National Council, NIE staff, and members of the research and educational communities that led to the adoption of the policy given above.

Examples of Basic Research

It is expected that in carrying out this policy, NIE will continue to associate support of fundamental research with the major program groups. Since 1974, NIE has been organized into six such program groups:

- Basic skills
- Finance and productivity
- School capacity for problem solving
- Educational equity
- Education and work
- Dissemination and resources.

Research priorities within each group will be discussed, and examples will be given of significant projects. In the grants competitions mentioned there is usually a range of projects supported, from applied to basic research.

Basic Skills

The basic skills program as a whole is concerned with the learning, teaching, and measurement of student achievement in reading, writing, basic mathematics, and with the current legislative interest in establishment of educational standards. It is concerned also with aesthetic education.

Learning. The major current research priority in the learning program is reading comprehension. As a result of conferences held in the summers of 1973 and 1974, involving scientists from a variety of fields and teachers of reading, the approach to reading comprehension is that of current thinking in cognitive psychology regarding the way human beings process verbal information. This approach stresses, for example, the importance of the reader's objective in reading a given piece of text and sees the process of comprehension as a fitting of what is being read to the content and conceptual structure of the reader's existing knowledge, rather than as an isolated assimilation of new information. Grants competitions (FY 1977, FY 1978) call for proposals in this area, and the FY 1978 competition includes proposals in the process of writing, based on a conference in summer 1977. The Center for the Study of Reading, established at the University of Illinois at Urbana-Champaign, is pursuing, with NIE support, a program of research in the area of reading comprehension.

In mathematics, a principal emphasis (with limited funds) is on applied research and development relating to educational opportunities provided by the availability of increasingly sophisticated hand-held calculators at low prices. In addition, a conference has laid out a preliminary agenda for research on fundamental processes in doing and learning mathematics, and proposals are invited in the FY 1978 competition.

Examples of projects and papers include:

John R. Anderson, Department of Psychology, Yale University, is developing and testing, with the use of a computer, a general model of human learning and cognition with emphasis on how children acquire cognitive procedures including skilled reading processes.

Wayne Wickelgren, Department of Psychology, University of Oregon, is testing the hypothesis that one of the ways in which skilled readers achieve high rates of speed is by making unconscious predictions about words that will appear in later sentences based on earlier words or sentences in a text.

Patricia A. Carpenter and Marcel Adam Just, Tracking Ongoing Comprehension Processes, in Carpenter and Just (Eds.) *Cognitive Processes in Comprehension,* Erlbaum Associates, Hillsdale, N. J., 1977 (in press). Authors use eye movements to clarify the role of context in comprehension.

Lawrence T. Frase, Purpose in Reading, in John T. Guthrie (Ed.) *Cognition, Curriculum, and Comprehension,* International Reading Association: Newark, Delaware, 1977, and Carl H. Frederiksen, Inference and the Structure of Children's Discourse, in R. Freedle (Ed.), *Discourse Processes: Advances in Research and Theory,* Erlbaum Associates, Hillsdale, N.J., 1977 (in press) report on work by NIE staff members.

Teaching. Research is increasingly supporting the generalizations that most students can learn most of what is expected of them given sufficient time on tasks and that teaching effectiveness depends more on longer term strategies fitted to the subject matter and other conditions than on individual minute-by-minute actions independent of context. Exploring these strategies and their relation to what is known about learning is a research priority at this time.

A conference of researchers and educators held in 1974 recommended a number of research directions. The Institute for Research in Teaching at Michigan State University is pursuing one of them—studies of teaching as clinical information processing. Another—investigating the nature of classroom discourse and its relation to learning—is the subject of a FY 1978 grants competition.

For example, in one project, Walter Doyle and Ruth J. Karth, College of Education, North Texas State University, are studying information processing responses that students use to interpret teachers' actions and to select strategies for learning.

Measurement and methodology. Valid measures and means of analyzing the data they yield are at the heart of any science. Currently there is considerable concern about the suitability of many existing tests for making judgments about student abilities, knowledge, skills, and learning difficulties. For example, tests are thought generally to be capable of measuring only a fraction of what is taught and learned, to be biased in favor of students from middle and upper class majority families, and not to be based on an understanding of learning processes. There is great interest in moving from norm-referenced tests—designed to spread students out on a spectrum, principally for administrative purposes—to criterion-referenced tests—designed to measure how much each student has learned of what was being taught. Although some of the work to be done in improving testing and analysis of test results can be regarded as technological development, there are also important basic questions to be addressed. The Measurement and Methodology Division is supporting such research through grants competitions.

For example, in one project, Robert B. Davis, Curriculum Laboratory, University of Illinois-Urbana, is developing a description of the cognitive growth process in the learning of elementary

mathematics as a basis for constructing tests of mathematical progress.

Educational adequacy. There is increasing public, legislative, and judicial interest in seeing that all students are educated to a level and capability necessary for participation in the society. The Educational Adequacy Division is supporting research projects aimed at providing a basis for arriving at educationally meaningful and legally enforceable standards through understanding of the correlation between skills learned and adult performance and of the likely effect of various laws and decisions. The FY 1978 competition calls for studies of the role of courts and legislatures in making educational policy, their use of scientific information, and the impact of their decisions on educational practice.

Finance and Productivity

The finance and productivity group is concerned with a variety of aspects of school and postsecondary finance and means by which education can make better use of its limited resources:

- A center is being supported at the University of Chicago to conduct basic and applied research and to provide a nationwide focus for scholarship in education, finance, and productivity. The center will study the ways in which education resources are raised, allocated, and distributed, and will seek to identify effective and efficient means of utilizing resources.
- The Center for Social Organization of Schools at Johns Hopkins University is studying the effects of classroom authority, task and reward structures, and student interactions on student motivation, achievement, and behavior. Other research of this nature may be supported through grants competitions in the future.

School Capacity for Problem Solving

The goal of this group is development or discovery of better ways in which schools and school systems can define their own problems, conceive and implement their own solutions, and assess progress toward improved organizational performance.

In 1974-75, NIE held six meetings with social and behavior scientists and educators to develop fruitful directions for research in organizational processes in education. Topics, drawn from modern organizational theory, included:

- Factors favoring and opposing change and adaptation in educational organizations
- Decisionmaking in educational organizations with ambiguous goals and uncertain means of achieving them
- Educational organizations as loosely coupled systems in which organizational charts do not give a true picture of the sources of action.

These meetings led to establishment of a continuing research grants competition in organizational processes in elementary and secondary education.

Educational Equity

The educational equity group seeks to provide a clearer understanding of the factors that limit educational opportunity for racial or ethnic minorities, women, students whose home language is not English, and students from low-income families. Research priorities include:

- Linguistic and other studies of learning by students from homes where English is not the primary language.
- Studies of social processes that contribute to educational inequity for women, studies of achievement patterns of men and women, and studies that evolved from a series of minority womens' conferences held during 1976.
- Studies of vandalism and disruption in schools, emphasizing identification of school characteristics that seem to invite disruptive behavior and those that promote students' social development.
- Studies of effects of varying desegregation patterns on school practice and student achievement, effects of teacher expectations on desegrated classrooms, and unequal status conditions in desegregated schools.

One example of a paper in this area is Jean Lipman-Blumen and Harold J. Leavitt, Vicarious and Direct Achievement Patterns, Counseling Psychologist, 1976, *6,* 26. (Dr. Lipman-Blumen is an NIE staff member.)

Education and Work

Programs within the education and work group are designed to:

- Improve understanding of the relationship between education and work.
- Help increase the contribution education makes to individuals' abilities to choose, enter, and progress in work that is beneficial to themselves and others.

Research grant competitions, based on conferences and state of knowledge studies, have called for proposals in the following areas:

- Factors and competencies in career decisionmaking processes, and their variation according to sex, sociocultural group, economic

status, and age.
- Pre-occupational interests in children and their relationship to or transformation into occupational choices.
- Competencies that are useful in a great number of occupations and their role in the process of job change and occupational mobility.
- Effect of selected cognitive, affective, educational, familial, or social factors on the achievement and participation of women in mathematics instruction and in occupations requiring mathematical competence.

Examples of projects include the following:

Zvi Griliches and Richard Freeman, Department of Economics, Harvard University, have been carrying out an econometric investigation of determinants and returns from schooling, training, and experience.

Stephen P. Dresch, Institute for Demographic and Economic Studies, New Haven, Conn., is studying mechanisms by which perceptions of career opportunities and career expectations are molded, constrained, and modified, and the effects of discrepancies between these perceptions and expectations and actual events.

Dissemination and Resources

The dissemination and resources group is concerned with making available the results of R&D on education in forms that will be useful to teachers, administrators, policymakers, parents, students, and other interested persons. It also supports and conducts activities to monitor the education R&D system, analyze its strengths and weaknesses, and recommend needed improvements.

Research sponsored by this group has included:
- Formulation and testing of conceptual frameworks in seeking to understand dissemination processes and the functioning of the R&D system for education
- Syntheses of research results and the search for new methodologies for knowledge transformation.

Organization and Management of Research Activities

NIE's legislation created the National Council on Educational Research, consisting of 15 members appointed by the President with advice and consent of the Senate, to "establish general policies for, and review the conduct of, the Institute." The Director of NIE and the Deputy Director are Presidential appointees. The Director "shall be responsible to the Assistant Secretary (for Education) and shall report to the Secretary through the Assistant Secretary." The statutory Deputy Director is primarily concerned with program, and there is now also a Deputy Director for Management. The organization of NIE consists of program groups, an Office of Planning, Budget and Policy Analysis, and an Office of Administration and Management. Each program group and office is headed by an Associate Director. Program plans are developed with guidance from the Director and Deputy Director by the staffs of program groups, and take account of:
- Congressional and executive mandates and concerns.
- Problems confronting education as seen by policymakers, educators, parents and students, persons in research and development, and other interested persons and groups, including minority communities.
- Promising directions for R&D arrived at in consultation with the R&D community through a variety of mechanisms, including agendizing conferences and studies involving leading scientists and educators.

Plans prepared by the groups are modified in response to reviews by the Director and Deputy Director and their staffs and are, of course, further reviewed in less detail by the National Council, HEW, the Office of Management and Budget, and the Congress.

NIE provides support for 17 R&D centers and regional educational laboratories. These are not Government-owned institutions, although they were created by the Office of Education and in many cases provided with buildings at Government expense. The R&D centers are located in universities, while the laboratories are independent, nonprofit institutions. Funding has been accomplished by contract, with changes in program requiring contract modifications. Through fiscal year 1977, the research program has been determined by NIE, although in many cases this has meant that a laboratory or center continued work on a program originally initiated by the institution. New legislation requires that beginning in FY 1978, plans will be solicited from the laboratories and centers within the context of NIE policies and programs. These will be reviewed by an independent national panel appointed by the Director of NIE, as well as by NIE staff. Final funding decisions will be made by the Director.

NIE supports basic research through a variety of mechanisms:

Research Grant Competitions

Currently, NIE research grant competitions typically derive from one or more interdisciplinary conferences of leading investigators and educators

which suggest promising directions for research in areas of concern. Examples are conferences on reading, teaching, writing, and organizational processes in education described earlier. The research grants announcements generally call for proposals in a rather broadly defined area such as reading comprehension, effective teaching strategies taking into account the instructional setting, and organizational processes in education. More specific research suggestions from the conference reports are included in announcements but are generally not prescribed. Grants announcements are subject to approval by the Director, and in contrast with other forms of procurement, by numerous units in the Office of the Secretary of HEW.

Proposals are reviewed by investigators from outside NIE as well as by NIE staff, and final decisions are made by the Director in response to staff recommendations. Review criteria are generally as follows, with some variation from program to program:

- The significance of the proposed research for American education, including the importance of the problem area from the standpoint of basic knowledge on problems of American education; and the likely magnitude of the addition that will be made to knowledge if the project is successful, including the generalizability of the results.
- The quality of the proposed research project, including such considerations as the extent to which the application exhibits thorough knowledge of pertinent previous work and relates the proposed research to it; the likelihood of the success of the project; and the adequacy of design, methodology, and instrumentation, where appropriate.
- The qualifications of the principal investigator and other professional personnel, as evidenced by their experience and previous research productivity; and the quality of the discussion and analysis in the application.
- The adequacy of the facilities and arrangements available to the investigator to conduct the proposed study.
- The reasonableness of the budget for the work to be done and the anticipated results.

The normal maximum duration of projects is three years, and funding is usually on a yearly basis, subject to satisfactory progress and availability of funds. In some cases, NIE plans to continue grants competitions in a specific area; in other cases, there will be only a single competition. A continuing program in the rather broad area of organizational processes in education has been mentioned above under "School Capacity for Problem Solving." A continuing, rotating study group reviews proposals and prepares syntheses of knowledge in the area.

Unsolicited Proposals

NIE accepts for consideration unsolicited proposals for various sorts of projects, including basic research, that do not fit into any current research grant competitions. Review is similar to that for proposals in grant competitions, except that proposals requesting less than $25,000 may be supported without external review.

R&D Centers and Regional Educational Laboratories

These institutions, described earlier, generally carry out development and associated applied research. However, some basic research is also pursued, particularly in the R&D centers, which are based in universities.

New Institutions

NIE has also created several new institutions with specified lifetimes. Examples of such institutions, which have been mentioned above, are:

- Center for Study of Reading (University of Illinois-Urbana and Bolt, Beranek, and Newman) and the Institute for the Study of Teaching (Michigan State University), which were created through requests for proposals (RFP's) derived in considerable part from conferences on reading and teaching, respectively.
- Finance and Productivity Center (University of Chicago), which was created through an RFP calling for plans to develop a conceptual framework and R&D agenda in educational finance and productivity, to provide national leadership in carrying out the agenda, and to carry out selected portions of the agenda.

RFP's are developed by NIE committees involving persons from inside and outside the cognizant group and are subject to approval by the Director. Proposals are reviewed similarly, with the addition of several reviewers from outside NIE.

As has been indicated, decisions as to what mechanisms are to be used for support of basic research are part of planning and budgeting.

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

Submitted by Raymond J. Struyk, Deputy Assistant Secretary for Research and Demonstration

HUD's Mission

The year of 1977 has been one of searching reexamination of the historic roles and missions of the Department of Housing and Urban Development (HUD). Our communities have suffered years of neglect, and many are edging close to fiscal disaster. Housing costs have climbed more rapidly than incomes and now owner-occupancy is no longer feasible for many ordinary families. Overt and subtle forms of discrimination continue to limit the neighborhood and housing choices of many families, and aid to the housing-poor has undergone stop-and-go turmoil.

In the face of this challenge, HUD's new leaders have rededicated the Department to its urban service role, with the following major mission objectives:

Revitalization of the Nation's urban areas. HUD seeks to revitalize the Nation's urban areas by:

- Preserving existing neighborhoods, using subsidies for existing housing, urban homesteading, rehabilitation programs, and new construction
- Providing incentives for middle income citizens to return to or remain in central cities
- Providing subsidized housing for low and moderate income persons who wish to stay in central cities
- Coordinating economic development with urban development initiatives and encouraging reinvestment in the neighborhoods, linking lenders, neighborhoods, and city governments.

Use of housing programs as aid to revitalization and to provide necessary shelter for all citizens. Through the use of housing programs, HUD seeks to:

- Expand supplies of housing for low and moderate income persons without regard to volatile economic changes
- Maintain existing housing supplies through major rehabilitation efforts; provide incentives for creation of an expanded rehabilitation industry
- Provide sufficient support services—social, commercial, and recreational—to ensure that subsidized housing is an integral part of revitalization effort
- Utilize housing assistance plans to their full potential as tools for using housing in revitalization efforts
- Use HUD inventory in imaginative ways to house the poor and aid revitalization.

Provision of freedom of choice in housing for all persons. HUD seeks to provide freedom of choice in housing in order to:

- Provide meaningful choices, i.e., establish different program options for different types of consumers
- Involve communities in suburban areas with interagency coordination to rationalize existing programs for sewers, water, mass transit, and jobs
- Advise people on the range of choices available and the concurrent responsibilities of such choices (counseling, technical services)
- Ensure that all people of all races and income levels have the opportunity to live where they choose—not just in cities, but suburbs and rural areas as well
- Coordinate various Federal housing programs in Farmers Home Administration, Veterans Administration, and HUD.

Increase in the capability of communities and neighborhoods to achieve revitalization. HUD seeks to help communities and neighborhoods in their revitalization efforts by:

- Facilitating the exchange of imaginative approaches and related knowledge
- Providing management expertise to aid communities in efficiently using State, local, Federal, and private funds
- Helping neighborhood groups to deal with the complexities of using available resources in revitalization and stabilization efforts.

HUD's research program is intended to provide the analytic capability to help the Department's top managers carry out these objectives. The development of effective operating programs and the selection of the best alternative among competing

proposals are heavily dependent on the availability of accurate data, understanding of complex program environments, and the capacity for rational analysis of these factors. This is true in any agency or department, but particularly important for HUD.

Research Program Perspective

Many of the phenonmena around which HUD must shape its programs are not yet well understood. Although most people have an intuitive understanding of the workings of their communities, analysis has begun to show that some community problems may have counterintuitive solutions, which ordinary experience and common sense might not have suggested.

For example, the Federal Housing Administration (FHA) programs, begun in the mid-thirties, were a magnificently innovative response to the need to restimulate homeownership after the depression. The introduction of the long-term, low down payment, equal monthly payment mortgages, now taken for granted, was thought to be extremely risky by conventional lenders at the time.

But 40 years later, if the effects of the FHA are examined objectively, one must conclude that its programs contributed strongly to the present problems of our center cities. Millions of middle-class families were given new choices, and they opted for suburban living, with the aid of FHA mortgages. The center cities were left with the very rich, the very poor, and all of the problems that followed. What member of the Congress or the Executive branch could reasonably have foreseen such a result?

The dynamics of community change are complex and interactive. To have anticipated the effects of FHA programs, policymakers would also have had to have known and taken into account the interactive effects of the massive Federal highway program, the increasingly general affluence and the rise of the two- and three-car family, the continued influx of the poor (including large numbers of illegal aliens) to the center city, the growth of crime, the deliberate self-insulation of suburban communities from center city problems, the rise of a strong union movement among local government workers, and many similar factors.

Because such complex and difficult considerations are involved in every new program, the urban policymaker must tread with great care. The urban researcher's position is equally difficult. Currently useful generalizations must not be oversold. The limitations of data and analyses must be made clear.

Role of Research

The scale and urgency of the day-to-day problems HUD faces make it necessary—and inevitable—that its research program be primarily focused on policy-relevant projects of applied research. With a relatively modest budget ($55 million for FY 1977), it has not been possible, however desirable, to address more fundamental questions of housing and community development, except as a subsidiary part of applied research projects, or except when applied work could not proceed without development of more basic knowledge.

By the classic definition of basic research (the search for pure knowledge for its own sake) and applied research (the search for a specific solution to a known problem, having direct application) nearly all of HUD's research would have to be classified as "applied research." We see our work not as "either/or" but a continuum, with some more basic in nature.

Urban study is among the most recent of the formal areas of scholarly interest to have emerged. It arises from an amalgam of other disciplines: Economics, political science, sociology, social psychology, demography, and the arts of architecture and urban planning. Most work to date has been in the class of case studies. Few are longitudinal. Few have had the relative luxury of control group observation. Few are generalizable from the local event to the national case. It is also unfortunately true that a great part of the work to date—the bulk of which has been conducted by individual researchers, at widely separate institutions, pursuing questions of their own interest—has had little relevance for local and Federal policymakers. It has been in a form either not accessible or not useful to a policymaker, or the questions studied have been too narrow or not generalizable beyond the particular case.

Examples of Research

HUD's research program has, in recent years, begun to correct past problems and to provide some direction and coherence to urban studies. It has done so by the example of the priorities and rising standards of its own work. This effort has not been sufficient, but it has been a start. HUD's new team of policymakers is strongly committed to improving further the relevance and quality of its own research and its leadership of the work of others in the field. It intends to widen the dialogue with its research counterparts in academia and industry, to communicate HUD's needs and priori-

ties more succinctly, to coordinate its work better with the needs of others, and to attempt to develop a consensus on priorities among the most urgent community research problems.

Often HUD's research office has been given immediate, urgent problems for solution, for which neither basic data nor underlying hypotheses existed. In order to respond to such problems, work first had to proceed on data gathering and development of hypotheses. Thus, despite budget restrictions and time pressures, HUD's research team found itself working at the more fundamental end of the research continuum.

An example of this was the phenomenon of housing abandonment, which emerged in the late sixties and early seventies. Despite a serious national housing shortage, particularly for lower income families, otherwise sound or rehabilitatable housing was being abandoned by its owners. In many instances the abandoned units were then vandalized or gutted by fire and permanently removed from the Nation's housing stock.

Before program interventions could be designed, an understanding of the phenomenon had to be obtained. What were its scope and prevalence? In what circumstances? Was there any pattern to it? What phenomena could be associated with it? Was it a single problem, or were there several related mechanisms at work? Could it be differentiated by location? Form of tenure? Type of occupant? Type or age of building? Could a plausible hypothesis, or hypotheses, be developed to explain the phenomenon? If so, was there a preferred point of intervention?

Our understanding remains imperfect, but much of the basic work has been done, and several promising Federal and local interventions have grown out of this work. Among these are:

- The urban homesteading program, under which HUD-mortgaged, abandoned properties, in selected neighborhoods, are sold for a nominal sum to families promising to rehabilitate the homes to code standards and to live in them for at least three years, while their communities provide a parallel program of improved neighborhood services.
- The Urban Reinvestment Task Force, funded by HUD and directed by the Federal Home Loan Bank Board (FHLBB), under which a tripartite group—local lenders, local government, and a neighborhood leadership organization, guided by the FHLBB national Task Force staff—develop a neighborhood fix-up, self-help, and rehabilitation loan program, intended to reverse a pattern of disinvestment and neighborhood decline.
- The distressed properties program, aimed at HUD-insured and HUD-subsidized suburban housing projects in which initial defaults and abandonments have begun a self-perpetuating spiral of further defaults and abandonment; the program intervention is the provision of incentives for private or local government-sponsored entities to step in, acquire, and repair all abandoned units, get them occupied on a rental basis, and provide homeownership opportunities when the housing sales market restabilizes.

HUD's Annual Housing Survey is a much broader quest for basic data, arising out of more immediate needs. Time and again, program questions and the design of options and alternatives suffered from the lack of sufficient, timely, reliable data on changes in the numbers, quality, and distribution of our housing stock and the characteristics of its occupants.

The decennial census provides much useful information but is not adequate for these needs. Fast-moving phenomena, such as the housing abandonment described above, could not wait 10 years to be counted; nor could data for evaluations of the impact of Federal housing and community development programs. In addition, the census must meet many needs. The number of questions devoted to housing and community development are, of necessity, limited. Thus the range and scope of census information, as well as its timeliness, have been inadequate for HUD's needs.

As an example, there has been a serious problem with data on substandard housing. An examination of census data indicates that the Nation has made very substantial progress in the years between the 1950, the 1960, and the 1970 censuses in the reduction of substandard housing. While there is no doubt that the trend is a true one, the implication that we have nearly overcome this problem is misleading. The census definition of "substandard" housing is inadequate to today's aspirations. (Substandard housing is defined by the census—in simplified terms—as not meeting certain health or safety standards.) We believe there is some housing that could meet that test and still be unsatisfactory. Suppose, for example, that it had no electrical service, or that it had no heating or insulation for a cold climate. The census definition also fails to account for housing that is not substandard itself, but is in a neighborhood or environment that is unsatisfactory (the last occupied house in an otherwise abandoned slum area, for example).

The first Annual Housing Survey (sample size 75,000 dwellings, approximately 0.1 percent of the total) was conducted for HUD through an interagency agreement with the U.S. Bureau of the Census in 1973. It is now providing HUD, and all other researchers and professionals in the urban field, with a long-needed flow of data upon which

a more informed level of analysis may be based. The data even raise new questions of their own. For example, all previous studies indicated that fear of crime was the most serious urban concern. Among sample survey respondents questioned about neighborhood problems severe enough to cause them to move, crime was not among the top factors. If validated by further study, these data could lead to shifts in current domestic program priorities.

In other instances, instead of responding to an existing emergency, HUD has attempted to direct its research to anticipate newly emerging problems or to provide data and tested alternatives prior to the adoption of large-scale new initiatives.

The most notable of these is the experimental housing allowance program (EHAP). This is the largest single social science research project yet funded. When completed, a total of approximately $175 million in research and operating subsidy program funds will have been devoted to it. Its purpose has been to test whether direct cash payments may be an effective alternative to the provision of housing units and services to the housing poor. It is examining three subquestions: (1) What are the possible alternative delivery mechanisms for such cash payments to eligible recipients; (2) what are the effects of such payments in actual housing markets; and (3) what are the behavior changes and potential benefits to the recipients of such housing assistance? Nearly 20,000 families in more than 10 cities will have participated in the experiment for as long as 10 years before the last parts of the project have been completed. It will have been a very large-scale simulation of multiple alternatives, prior to the implementation of any operating program. The work is a first of its kind for any housing program, and is also providing insights into the more general problem of welfare reform.

As a consequence of this research, a richness and diversity of detail is being obtained about the behavior of housing market participants (occupants, landlords, lenders, service agencies, local government, developers, suppliers, sales and management firms, etc.), never before available. Its availability and analysis will provide insights of the most fundamental kind, going well beyond the bounds of this particular demonstration.

We have other work that falls between our short-term, firefighting studies and the kind of anticipatory research represented by EHAP.

The current policy emphasis on the preservation of our existing neighborhoods and housing stock arises, in part, out of earlier analyses by HUD's research program. A corollary of that analysis was the need for improved housing management, especially in the use of our existing public housing stock. This led to a series of projects in this field, an initiative that continues today. Among the most important of those projects has been a five-year study of the qualities that make for "good" public housing management.

An important—and somewhat counterintuitive—finding has been that good Public Housing Authority (PHA) management is less costly than bad. That is, when measured objectively by the condition of the buildings and grounds and subjectively by the satisfaction of the tenants, well-managed projects were found to cost less to operate, per dwelling unit, than projects in which the buildings were poorly kept and tenant satisfaction was low. This finding had an important impact on program subsidies and is described below. In general, good management was also found to be decentralized, responsive, and firm—qualities that had not previously been seen by many PHA directors as keys to successful management. Even a small shift toward improved management practices among such managers could help restrain the rapid growth of Federal PHA operating subsidies (from $30 million in 1969 to $600+ million in 1977).

The growth of PHA operating subsidies is also held down by another application of our housing management research. It is perhaps the most significant use of social science research by HUD, or possibly any other Federal agency. The operating deficits of PHA's grew from the twin pressures of reduced income (a statutory change had fixed a limit of 25 percent of tenant income for rent) and inflation. In April 1975, a performance funding system was introduced, based on our research. Under it, subsidy to any PHA is limited to an average range of the amounts needed to operate high-performing PHA's found in our study, but adjusted for each individual PHA by factors beyond the direct control of management, such as the age of buildings, to assure the system's responsiveness to individual circumstances. To our knowledge, this is the first use of research, in any domestic program, to determine a fairer means to allocate Federal subsidies. PHA's whose management costs were too high were not left unaided; parallel programs were devised to help such PHA's reduce waste and improve efficiency.

Another current major effort of HUD research, in an entirely different field, is the residential solar energy program. Approximately 20 percent of the Nation's daily energy use goes to heating, cooling, and lighting our dwellings. In addition to strong conservation efforts, alternate energy sources must be found if we are to reduce this load. Solar energy is such a source, and hardware already exists for residential applications. Unfortunately, much of it is not yet cost-effective at today's custom-produced prices. It is expected there may be sub-

stantial economies in volume production, but many producers have been unwilling to gear up for an uncharted market.

Through this demonstration, HUD, in cooperation with ERDA, is attempting to stimulate that market, to provide incentives to both producers and consumers, and to define standards of quality and performance. The very size of the demonstration (more than 6,000 dwelling units) has given impetus to the market. The demonstration is also providing an opportunity to examine related issues in real-life settings. What should a solar owner's "sun rights" be, and how may they be assured against encroachment by others? Who installs the solar system? Who services it? What code requirements should apply? Can lenders be induced to recognize that higher first costs will be partially or totally offset by lower operating costs, and thus should justify higher loans?

Significant Opportunities for Future Research

HUD's current highest priorities for research are the following subjects:

- Reasons for the rise in the costs of housing, and means of controlling it
- Alternative mechanisms for financing subsidized housing to encourage better maintenance
- Ways to assist older cities in their economic development and financial problems
- New approaches to providing for the housing needs of the elderly and handicapped
- Neighborhood reinvestment and revitalization
- Development of procedure for selecting sites for subsidized housing and, more generally, for fostering stable racial and economic integration.

HUD is a young agency. Its research program is even younger. Much of its research lies in areas not previously well investigated, and progress relies upon diverse disciplines not yet well integrated. The opportunities for further work are broad. The needs are great, particularly in developing greater understanding of the fundamental processes with which we are dealing.

Whether any substantial additional resources can be devoted to such work in the near term, due to the press of more immediate concerns, remains in question.

There is no question, however, that much remains to be done. Questions still exist as basic as: "How can we predict the effects of various kinds of changes on our communities?" "Is the ancient role of cities as mothers of commerce, culture, and innovation undergoing eclipse as a result of advances in communication, transportation, and other technology?" "Are growth, decay, and other organic descriptions actually appropriate for the processes at work in communities?" (If "grow or die" does apply, the consequences are very far reaching.)

The true role and value of housing in our lives also remains under question. It has long been argued by housing advocates that it is one of the "merit goods" (a product or service having such merit or value to the community that it deserves support or funding by the community above the value individual users might place on the product). It has been argued that the provision of safe, sound, and decent housing leads to many broad benefits for its occupants, or that its absence is detrimental.

The bulk of studies done to date offer little conclusive support for such arguments. This has given opponents of special treatment for housing some comfort. It would be equally fair to state that those studies also offer little basis to refute "merit good" arguments. In many cases, it will take large-scale, long-term, carefully controlled studies to settle these arguments. Such studies remain as yet undone in the housing field.

Many other value judgments about housing and community affairs are accepted intuitively but remain unproven in any rigorous way. The values of owning a home are the basis for multibillion dollar programs. For example, the benefits of income tax deductions for property taxes and mortgage interest now exceed $15 billion annually. Homeownership is thought to provide better and more stable citizens by giving them a "stake" in the community. It probably does, but it has yet to be carefully documented.

Our equal opportunity goals call for HUD projects to be broadly mixed socially, racially, and by income level. The broad mix meets egalitarian ideals. It is said to provide role models for upward mobility and better representation in community affairs for the less fortunate, and to provide a broadening environment for the more fortunate. It is likely that such benefits occur, but no studies exist that conclusively show this to be true.

We are heavily committed to neighborhood preservation and revitalization, but we do not know whether current modes of intervention may have unwanted side effects, such as the family relocation problems and small business disruption that affected earlier renewal efforts.

General revenue sharing and special purpose block grant programs have removed many of the Federal controls on community use of Federal funds, in an attempt to restore the decisionmaking

powers of local general-purpose government. However, we do not know whether the sum of such local decisions will give adequate recognition to national concerns, particularly for those groups having special or minority needs.

Rental housing remains a continuing need for many families, but in a time of growing consumer protest, changing landlord/tenant rights, rent control, high mortgage interest, high property taxes, spiraling energy costs and wage rates, and difficulties in obtaining satisfactory maintenance and repair services, rental housing no longer seems an attractive risk to many investors. Diminished multifamily building activity, condominium conversions of existing units, and multifamily building abandonments are supporting signs of this. But these indications are not yet confirmable as hard fact, and in the meantime Federal tax reform and other policies may be adopted that may further reduce investment incentives in rental property.

Local and Federal tax policies appear to encourage "urban sprawl" by making it cheaper for landlords to operate a newly built unit in a suburban location than an existing unit in the city. They also appear to discourage urban property rehabilitation through increased assessments for improvements, thus perhaps helping to perpetuate building and neighborhood decay. Suggestions for tax reform go back many years, yet the data and information available to policymakers evidently have not been convincing enough to bring change.

We have much scattered data on the families currently served by HUD programs but not in an easily usable form. However, we have relatively little data on those with serious housing needs or those eligible for HUD programs. In a recent intra-government discussion of program options, it was thus possible for two major agencies to disagree widely on the percentage of eligibles currently being served.

The problems of crime, vandalism, and security in housing remain of great concern. Much of the effort to deal with these problems has gone into hardware and fortress-like solutions, despite the fact that such data as are available indicate that fortress solutions are seldom effective and often increase the fears of occupants. Recent intuitive, "territorial" solutions, based on group action and relatively minimal structural change, appear promising, but we do not yet have definitive results on which to require a shift in program direction.

The foregoing examples have merely been illustrative of the great diversity and scope of basic questions in the urban housing field. They represent problems that touch nearly all our citizens in a direct and often profound way. It is urgent that we find and focus resources to resolve them.

DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

Submitted by Anthony Raspolic, Acting Deputy Assistant Secretary of the Interior

U.S. GEOLOGICAL SURVEY

Submitted by V.E. McKelvey, Director

NATIONAL PARK SERVICE

Submitted by Dr. Albert G. Greene, Jr., Deputy Chief Scientist, National Park Service

U.S. FISH AND WILDLIFE SERVICE

Submitted by Robert E. Putz, Deputy Associate Director

OFFICE OF WATER RESEARCH AND TECHNOLOGY

Submitted by James S. Burton, Acting Director

BUREAU OF RECLAMATION

Submitted by Anthony Raspolic, Acting Deputy Assistant Secretary of the Interior

BUREAU OF MINES

Mission of the Bureau of Mines

The Bureau of Mines statement of mission is as follows: To ensure the continued viability of the domestic minerals and materials economy and the maintenance of an adequate minerals base so that the Nation's economic, social, strategic, and environmental needs can be better served.

Metallurgy's mission is to provide, through R&D, the scientific and technical information necessary to encourage and stimulate the nonfuel minerals industry to make advancements in technology that will result in an adequate and continuing supply of mineral raw materials at acceptable costs and with a minimum of waste and environmental degradation.

Definition of Basic Research

The research activities of the Bureau relate to mission-oriented basic research where the investigators are concerned primarily with gaining a fuller knowledge or understanding of the subject under study for the purpose of solving problems concerned with advancing technology that will result in sufficient mineral raw materials at acceptable costs and with minimal waste and environmental harm.

Role of Basic Research

The Bureau believes the role of its basic research is to conduct such programs of inquiry as are necessary to stimulate adequately the private sector in the production of minerals and to supply an appropriate and substantial share of the national needs in a manner that is acceptable and in the public interest. It is of special interest that methods used to accommodate the material needs be such that waste of material is minimized, and that mineral raw materials are supplied and mineral-based products are used and disposed of without objectionable social and environmental costs. The Bureau's concern is directed to the best method by which current and emerging demands may be met, the real cost of such achievements, and the assessment of related socioeconomic factors.

Examples of Basic Research

Below is a list of the 10 most significant projects involving basic research (intramural and/or extramural) carried out by Metallurgy in the past 10 years:

- Iron from nonmagnetic taconites. This project resulted in the production of four million annual tons of high-grade iron oxide pellets, the first large-scale commercial venture in processing nonmagnetic taconite. The plant, located at Tilden, Michigan, represents an industrial investment of $200 million.
- Electrooxidation for gold extraction. This new method for processing carbonaceous ores constitutes the biggest breakthrough in gold technology since the turn of the century.
- Blast furnace research. Research on blast furnace technology conducted with a consortium of 22 major American steel companies resulted in reduction in cost for the production of pig iron by an estimated $500 million per year.
- Raw refuse reclamation plant. The raw refuse process incorporates conventional mineral processing operations to separate and recover metal and mineral values from raw, unburned urban refuse.
- Thermodynamic properties of selected inorganic compounds. Critical evaluation of worldwide thermodynamic literature on copper and nickel, and their compounds, was completed.
- Rare-earth recovery. Methods were developed for recovering rare-earth elements from complex rare-earth mixtures.
- Microgrinding industrial minerals. Research was conducted on development of an attrition grinder capable of grinding mica and other tough minerals.
- Uranium recovery from mine waters. Methods of recovering uranium from waste mine waters were researched.
- Reactive and refractory metal casting. Bureau research conducted during the past decade has been a major contributor to industrial development of reactive and refractory metal casting technology.
- Smokeless auto incinerator. Research was conducted on development of a pollution-free auto incinerator for use by small processors of junk cars.

The most significant projects involving basic research carried out in the past 10 years by the Mining Office include:

- Suppression of coal dust explosions
- Inhibition of methane-air flamer
- Coal dust ignition

- Spontaneous combustion
- Physics of adhesion of coal aerosols
- Fluid dynamics of small particle transport and deposit
- Spontaneous electrostatic precipitation of dust
- Fundamentals of wet dust suppression
- A study of the importance of the airborne particulate matter to the transport of radon in mine atmosphere (at the University of Illinois).

Current and Future Research Emphasis

Five interesting agency projects involving basic metallurgy research which currently are in progress are listed below:

- Fundamentals of flotation. The objective is to improve the efficiency of recovery of mineral and metal values from ores and concentrates in processes governed by solid-liquid interfacial phenomena in flotation and direct electrochemical reduction.
- Florida phosphate slimes. The objective is to investigate and develop methods of reducing the pollution caused by the colloidal waste fines and process effluent from the mining of phosphate fertilizer.
- Catalyst development and characterization. The objective is to develop low-cost rare-earth metal catalyst materials to replace expensive catalysts.
- Ion implantation for surface alloys. The objective is to implant thin skins of chromium and similar metals on base metals.
- Improved methods of iron ore pellet production. The objective is to develop and demonstrate systems for utilizing coals of various ranks suitable as fuel in firing iron ore pellets.

Five of the most interesting agency projects involving current basic research in the Mining Office include:

- Development of effective means for preventing, suppressing, and extinguishing fires and explosions
- Nature of explosive gas mixture
- Explosion propagation
- Dust capture by water droplets
- Dynamics of small particle transport.

Short-term research priorities for the next three years include projects to:

- Provide fundamental thermodynamic data and process evaluations, in support of Bureau research, essential to the development of minerals processing technology.
- Devise new and improved phosphate rock processing methods to improve recovery, reduce processing losses, control contaminants, and minimize slimes disposal problems.
- Develop a sound data base of mineral reserves, production, and consumption for determining longer range priorities.
- Develop improved techniques for detecting impending rock bursts.
- Develop improved fire suppression systems for mines.
- Develop improved processing technology for the prompt, economical recovery of copper and byproduct metals from ores, concentrates, and mine wastes.
- Test, improve, and evaluate, on a comparative basis, promising technologies for recovering alumina from domestic nonbauxitic resources, to lessen U.S. dependence on imported bauxite and alumina.
- Develop improved beneficiation methods for recovering nonmetallic minerals from domestic ores and/or mineral wastes.
- Develop improved technology for recovering uranium from various low-grade, domestic refractory carboniferous and silicious uraniferous resources.
- Provide basic physical/chemical data in support of the alumina miniplant project.
- Evaluate wet high-intensity magnetic separators as a means of concentrating iron-bearing materials.
- Apply advanced techniques to improve concentration of chromite from complex domestic sources.
- Extend the application of extraction technology to 0.01 percent uranium resources.
- Provide methods for identifying, measuring, and controlling fugitive and accessory elements and compounds that are present in minerals processing systems and pass through into the waste streams or the atmosphere.

Long-term research priorities for the next 10 years include projects to:

- Devise wider uses for more abundant domestic minerals as substitutes for critical materials and commodities in short supply.
- Develop economic methods to recover minerals and metals from domestic ores of progressively lower grade and complexity.
- Develop technologies to facilitate the complete recovery of minerals now wasted during processing.
- Develop metallurgical processes that use less energy or use low-cost sources of energy.

- Provide technology to increase the portion of U.S. metal and mineral needs met by secondary resources.
- Develop recovery techniques and stimulate a significant increase in recycling metal and nonmetallic materials from industrial and obsolete consumer scrap materials.
- Develop a better technologic base for metallurgical processing systems so that appropriate environmental regulations and control technologies can be implemented which will prevent environmental degradation without unnecessarily restricting efforts by the minerals industry to meet the Nation's mineral needs.
- Effectively minimize the undesirable environmental effects that can result from mineral processing operations by providing better processing technology.
- Evaluate, demonstrate, and promote expanded use of secondary materials in various metal alloys or nonmetal products.
- Anticipate and project new scrap materials to allow early development of processing and recovery techniques.

Listed below are some promising or vital areas of research, not now supported but involving basic research, that warrant increased emphasis and support:

- Deep brine scaling mechanisms and kinetics
- Simulation of experimental metallurgical and engineering research using computer modeling.
- Magnetic and electrostatic advanced mechanisms that have potential for separation of the mineral constituents of low-grade and complex ores.

Below are some significant research papers published during the past 10 years:

MINERAL PROCESSING

Frass, F., "Magnetic Separation of Minerals of Low Susceptibility and Small Particle Size."

Frommer, D.W., "Aspects of Water Reuse in Experimental Flotation of Nonmagnetic Taconites."

Browning, J.S., "Mica Beneficiation."

Stanczyk, M.H. and Feld, I.L., "Ultrafine Grinding of Several Industrial Minerals by the Attrition Grinding Process."

George, L.D., Cochran, A.A., and Waters, R.R., "The Waste-Plus-Waste Method for Recovering Metals From Electroplating Wastes."

Henrie, T.A. and Lindstrom, R.E., "Hydrometallurgical Treatment of Sulfide Ores for Elimination of SO_2 Emissions by Smelters."

MacDonald, D.J., May, A., and Baglin, E.G., "Stability Constants of Metal Coordination Compounds, Complexes of N-Ethylethylenediamine and 2-(Ethylthio)-Ethylamine."

Rosenbaum, J.B., George, D.R. and May, J.T., "Metallurgical Application of Solvent Extraction (in two parts) 2. Practice and Trends."

Scheiner, B.J., Lindstrom, R.E., Guay, W.J., and Peterson, D.G., "Extraction of Gold From Carbonaceous Ores: Pilot Plant Studies."

Scheiner, B.J., Lindstrom, R.E., and Shanks, D.E., "Recovery of Mercury From Cinnabar Ores by Electrooxidation."

Brown, M.H. and Taylor, Jr., A.R., "Heats of Solution and Formation of Oxalic Acid and Some Alkali Metal Oxalates."

George, D.R. and Ross, J.R., "Improved Eluex Process for Eluting Uranium from Ion Exchange Resins."

Pankratz, L.B. and Weller, W.W., "Thermodynamic Data for Ferric Sulfate and Indium Sulfate."

Ross, J.R. and George, D.R., "Recovery of Uranium from Natural Mine Waters by Countercurrent Ion Exchange."

ELECTROMETALLURGY

Henrie, T.A., Morrice, Jr., E., and Murphy, J.E., "Method for Production of High-Purity Samarium Metal."

Marchant, J.D., Shedd, E.S., Henrie, T.A., and Wong, M.M., "Electrotransport of Impurities in Rare-Earth Metals, Using a Pulsed Current."

PYROMETALLURGY

Clites, P.G. and Beall, R.A., "Inductoslag Melting of Titanium."

Douglas, T.B. and King, E.G., "High-Temperature Drop Calorimetry."

Henrie, T.A., "Extractive Metallurgy of Titanium." Chapter 11 in "High Temperature Refractory Metals."

Kleespies, E.K. and Henrie, T.A., "Reaction Rate of Titanium and Titanium Alloys with Titanium Lower Chlorides."

Calvert, E.D., Beall, R.A., and Kato, H., "Electroslag-Melted Molybdenum."

Hill, S.D., Block, F.E., and Mrazek, R.V., "Heat and Mass Transfer in Kroll Process Titanium Sponge During Salt Evaporation."

King, E.G., Mah, A.D., and Pankratz, L.B., "Thermodynamic Properties of Copper and Its Inorganic Compounds."

Nafziger, R.H. and Calvert, E.D., "Electroslag Melting of Zirconium and Selected Properties of Fabricated Material."

Nafziger, R. H. and Riazance, N., "Alkaline-Earth-Fluoride-LaF_3 Systems with Implications for Electroslag Melting."

U.S. Bureau of Mines. "Control of Sulfur Oxide Emissions in Copper, Lead, and Zinc Smelting."

Mah, A.D. and Pankratz, L., "Contributions to the Data on Theoretical Metallurgy," XVI. "Thermodynamic Properties of Nickel and Its Inorganic Compounds."

Hale, R.W., "Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing (Phase 4—Energy Data and Flowsheets, High-Purity Commodities)."

ADAPTIVE METALLURGY

Hyde, G.R., Maust, E.E., and Furlong, L.R., "Yttria and Dysprosia as High-Temperature Thermistor Materials."

SECONDARY RESOURCE RECOVERY

Frass, F., "Ionized Fields in Electrostatic Separation. Application to Secondary Materials."

Kleespies, E.K., Bennetts, J.P., and Henrie, T.A., "Gold Recovery From Scrap Electronic Solders by Fused-Salt Electrolysis."

Munson, R.A., "Properties of Natural Zeolites."

Norman, L.D. and others, "Computer Simulation of Particulate Systems."

Schwaneke, A.D., "Development of a New High-Temperature Solder System."

Frommer, D.W., Wasson, P.A., and Veith, D.L., "Flotation of Marquette Range Nonmagnetic Taconite Using Innovative Procedures."

Marr, H.E. III, "Six Models for Interelement Correction in X-Ray Analysis."

Maust, E.E., Jr., Richardson, P.E., and Hyde, G.R., "A Conceptual Model for the Role of Oxygen in Xanthate Adsorption on Galena."

Reimers, G.W., Rholl, S.A., and Khalafalla, S.E., "Device and Process for Magneto-Gravimetric Particle Separation Using Non-Vertical Levitation Forces."

Baur, J.P., Gibbs, H.L., and Wadsworth, M.E., "Initial-Stage Sulfuric Acid Leaching Kinetics of Chalcopyrite Using Radiochemical Techniques."

MINING RESEARCH (EXPLOSIONS)

Biordi, J.C., Lazzara, C.P., and Papp, J.F., "Flame Structure Studies of CF_3Br Inhibited Methane Flames, II. Kinetics and Mechanisms."

Burgess, D., Murphy, J., Zabetakis, M.G., and Perlee, H.E., "Volume of Flammable Mixture Resulting from the Atmospheric Dispersion of a Leak or Spill."

Grumer, J., "Recent Research Concerning Extinguishment of Coal Dust Explosions."

Kuchta, J.M., Bertzberg, M., Cato, R., Litton, C.D., and Burgess, D., "Criteria of Incipient Combustion in Coal Mines."

Hertzberg, H., Litton, C.D., Donaldson, W.F., and Burgess, D. "The Infrared Radiance and the Optical Detection of Fires and Explosions."

Richmond, J.K. and Liebman, I., "A Physical Description of Coal Mine Explosions."

Furno, A.L., Cook, E.B., Kuchta, J.M., and Burgess, D.S., "Some Observations on Near-Limit Flames."

Hwang, C.C., Chaiken, R.F., Singer, J.M., and Chi, D.N.H., "Backing of Hot Gas and Smoke Against Ventilation in Duct Fires: A Two-Dimensional Approach."

Hertzberg, M., Johnson, A.L., Kuchta, J.M., and Furno, A.L., "The Spectral Radiance Growth, Flame Temperatures and Flammability Behavior of Large Scale, Spherical, Combustion Waves."

Biordi, J.C., Lazzara, C.P., and Papp, J.F., "An Examination of the Partial Equilibration Hypothesis and Radical Recombination in 1/20 atm Methane Flames."

Lee, C.K., Chaiken, R.F., and Singer, J.M., "Charring Pyrolysis of Wood in Fires by Laser Simulation."

Burgess, D. and Hertzberg, M., "The Flammability Limits of Lean Fuel-Air Mixtures. Thermochemical and Kinetic Criteria for Explosion Hazards."

Biordi, J.C., Lazzara, C.P., and Papp, J.F., "Concentration Profiles for Radical Species in a Methane-Oxygen-Argon Flame."

Biordi, J.C., Lazzara, C.P., and Papp, J.F., "The Rate Coefficient for $H + CH_4 + H_2 + CH_3$ in the Temperature Range 1300-1700°K."

Biordi, J.C., Lazzara, C.P., and Papp, J.F., "Molecular Beam Mass Spectrometry Applied to Determining the Kinetics of Reactions in Flames. I. Empirical Characterization of Flame Perturbation by Molecular Beam Sampling Probes."

Papp, J.F., Biordi, J.C., and Lazzara, C.P., "Molecular Beam Mass Spectrometry Applied to Determining the Kinetics of Reactions in Flames. II. Critique of the Method for Rate Coefficient Determinations."

Hertzberg, M., Litton, C.D., Donaldson, W.F., Kuchta, J.M., and Furno, A.L., "The Spectral Growth of Expanding Flames. The Infra-Red Radiance of Methane-Air Ignitions and Coal Dust-Air Explosions."

Hertzberg, M. and Litton, C.D., "Studies of Incipient Combustion and Its Detection."

Organization and Management of Research Activities

The Associate Director—Mineral and Materials Research and Development is responsible for management of all the Bureau's R&D programs directed to the extraction, processing, use, and disposal of minerals, and research related to mineral-based substances and their wastes. Guidelines for research programs are developed by the Director's staff in Washington from information on the needs of the Nation for mineral materials. These guidelines are sent to the various field organizations where research personnel initiate ideas and proposals for achieving objectives identified in the guidelines. Review of research ideas and proposals is accomplished principally at the headquarters staff level. Evaluation is conducted by the professional scientists and engineers of the Washington headquarters staff.

The Assistant Director—Metallurgy and the Assistant Director—Mining are the principal Bureau of Mines authorities on current technology and areas of research relating to mining and metallurgical processes. They also recommend and implement authorized research programs.

Support of research by grant or outside contract in industry, universities, and in nonprofit institutions is determined after review. During the review process, unsolicited proposals are appraised for merit by members of the scientific and engineering

community outside the Federal Government, in addition to in-house review. Proposals are assessed from a technical standpoint to determine their importance to the basic objectives and aims of the Bureau. In general, proposals are supported in order of merit to the extent permitted by available funds. In cases of proposals of substantially equal merit, consideration is given to the general subject matter coverage of grants made in the program.

U.S. GEOLOGICAL SURVEY

Geological Survey's Mission

The U.S. Geological Survey was created in 1879 to study the geological structure and mineral resources of the public domain and to provide information to support development of the West. Congress and the Secretary of the Interior later expanded the Survey's responsibilities to include topographic mapping; chemical and physical research; stream gaging and water-supply assessments; supervision of mineral exploration and development activities on Federal and Indian lands; engineering supervision of water power permits; and administration of a minerals exploration program.

Although the emphasis and balance of the Survey's programs have changed over the years, they still reflect the fact finding mission described in the brief authorizing legislation of 1879. Today, that mission has two major objectives. First, the Survey is charged with increasing the knowledge of the extent, distribution, character, and origins of the Nation's earth resources and of the geologic processes that affect the use of the land so that man may adjust his activities to the constraints imposed by the environment and so that the Earth's resources may be managed wisely. Second, and no less important, are the Survey's regulatory responsibilities—classifying Federal lands and supervising mineral lease development on Federal and Indian lands.

Both missions call for objective and impartial reporting of investigations, identification of natural constraints on land use and resource development, and analyses of the consequences of alternative policies or actions related to resource development, conservation, and environmental protection.

Definition of Basic Research

The Geological Survey's operating definition of basic research is research that advances man's understanding of earth science and related natural science processes and phenomena.

Role of Basic Research

Most of the activities of the Survey are founded on the information gained from the basic research program. In short, basic research is the cornerstone of the Geological Survey's mission.

An appreciation of the breadth and scope of current Geological Survey research activities can be gained from U.S. Geological Survey Professional Paper 1000, "Geological Survey Research 1976"—a 400-page summary of significant results in the following topic areas:

- Mineral resource and mineral fuel investigations
- Regional geologic investigations
- Water resource investigations
- Marine geology and coastal hydrology
- Management of natural resources on Federal and Indian lands
- Geologic and hydrologic principles, processes, and techniques
- Geology and hydrology applied to hazard assessment and environment
- Remote sensing and advanced techniques
- Land use and environmental impact
- Topographic surveys and mapping.

Examples of Basic Research

Recent basic research related to the above topical areas has resulted in substantial advances in knowledge in a number of fields, including:

- Mineral- and energy-resource assessments using refined geologic, geochemical, and geophysical techniques
- Geologic hazards investigations—earthquakes, landslides, volcanic eruptions
- Geodynamics—investigations of the geologic composition and structure of the continental crust, outer continental shelf (OCS), and deep ocean crust
- Application of numerical methods to the solution of mass and momentum equations to fluid flow, both for ground water and surface water

- Development of orthophotomaps, which combine photographic imagery with some of the elements of a conventional topographic map to provide better portrayal of certain areas, such as large swamps and deserts
- Applications of physics to heat and chemical transport in water sufficient to make quantitative predictions possible
- Advancements in chemical and geophysical analytical techniques, including geochronometric, geothermometric, and geobarometric, telluric, electromagnetic, and geomagnetic studies
- Development of analytical (computational) methods of establishing geographic positions and elevations by means of aerial photographs and computer programs
- Development of an equilibrium-based understanding of major geochemical environments in water
- Development of statistical techniques applicable to rainfall runoff, flood frequency, and sediment transport
- Environmental studies in geology as related to man's modification of the Earth's surface (resource development, reactor siting, dam siting, and transportation)
- Optometric research into the special conditions and problems of drawings made from stereoscopic pairs of aerial photographs
- Lunar and planetary geology and exploration in cooperation with NASA
- Development of methods to use Doppler satellite observations for rapid, highly accurate surveys in remote areas, such as Antarctica
- Development of methods to transmit effectively earth science information to the user community
- Development of geophysical theory of internal stresses in rocks sufficient to describe the mechanics of hydraulic fracturing
- Development of methods of using multispectral imagery from Landsat to solve many problems in small-scale mapping and to provide consistent views of large areas of the Earth's surface
- Development of a theory explaining surging and retreating of glaciers.

Current and Future Research Emphasis

Current and near-future basic research in the Geological Survey is expected to follow traditional lines of inquiry, with special emphasis placed on:

- Developing improved methods of assessing mineral and energy resources, including geothermal resources
- Improvement of the understanding of geodynamics, the forces and processes from within the Earth that affect crustal features, such as the continental plates and the oceanic basins
- Improving techniques of transmitting earth science information to user groups
- Improving methods of predicting and assessing the occurrence and effects of geologic hazards, such as earthquakes, volcanic eruptions, and landslides
- Describing surface- and ground-water transport of solutes
- Describing dynamics of ecological systems, especially with regard to estuaries
- Developing interdisciplinary approaches to the understanding of water quality, including biological controls of heavy metals in sediment
- Improving water-quality sensor technology
- Developing an aerial profiling of terrain system, to establish ground position with an accuracy of 3 meters horizontally and 0.15 meters vertically
- Developing a digital cartographic data bank for computer-controlled storage, processing, and retrieval in various forms of the kinds of information shown on general-purpose topographic, land-use, and land-cover maps
- Determining Earth natural resources and physical conditions using remote-sensing techniques.

Other areas of inquiry related to certain segments of the Geological Survey programs not presently funded include studies of cyclic changes in climate, paleoclimate of ancient land areas, stochastic hydrology, and the basic physical properties of water.

Organization and Management of Research Activities

The scientific and regulatory missions of the Geological Survey, all of which include basic research, are carried on by five major organizational units:

- The Topographic Division produces maps delineating the physical features of land areas in the United States, its outlying areas, and Antarctica and conducts research into advanced mapping methods. The Division also collects and distributes information on the availability of aerial photographs and space images, maps and charts, geodetic data, and related cartographic information through its National Cartographic Information Center (NCIC).

- The Geologic Division, through research on geologic processes and Earth history, provides information that permits intelligent adjustment to the natural environment and wise use of the Earth's resources. The Geologic Division determines the composition and structure of the rocks and materials that lie at and beneath the Earth's surface, identifies potential energy and mineral resources including those of the OCS, and develops and distributes knowledge about natural processes, Earth history, and natural hazards, such as earthquakes, volcanic eruptions, and land subsidence.
- The Water Resources Division researches hydrologic processes, assesses the quantity and quality of the Nation's water supply, develops the knowledge necessary to predict the environmental consequences of alternative plans for developing water resources, coordinates Federal water data-acquisition activities, collects and distributes information about the availability of water data through the national water data exchange (NAWDEX), and develops and distributes information about natural hazards such as floods and land subsidence.
- The Conservation Division classifies the public lands with respect to leasable minerals and water power sites, and supervises exploration and development authorized by the Secretary of the Department of the Interior under leases and permits on Federal and Indian lands.
- The Land Information and Analysis Office coordinates and administers interrelated interdisciplinary programs of both the Department of the Interior and the Geological Survey with the objective of interpreting and displaying resource information in ways that are readily accessible and understandable to a wide range of potential users, particularly land-use planners and decisionmakers.

These research, fact finding, and regulatory programs receive executive direction from the Office of the Director and technical and administrative support from the Administrative, Computer Center, and Publications Divisions. Total funds obligated by the Geological Survey in fiscal year 1976 amounted to $345 million, an increase of $15.2 million over fiscal year 1975. Obligations from appropriated funds in fiscal year 1976 provided about 75 percent of the total funds available to the Survey. The remaining 25 percent was from Federal, State, and local agencies, and from miscellaneous non-Federal sources.

The allocation of funds to the Survey's five principal budget activities (topographic surveys and mapping, geologic and mineral resource surveys and mapping, water resources investigations, conservation of lands and minerals, and land information and analysis), which had been changing dramatically in the past few years, remained relatively unchanged in fiscal year 1976.

Funds to support Survey programs come from two sources: (1) an annual congressional appropriation, and (2) reimbursements from Federal and non-Federal agencies. Federal funds, under the title "Surveys, Investigations, and Research," support the Survey's directly appropriated programs under each budget activity. Other funds from State and local agencies, Federal agencies, permittees and licensees of the Federal Power Commission, foreign countries, and international organizations pay for various information products and services provided by the Survey's reimbursable programs.

Whereas directly appropriated programs are aimed at resource investigations and research on problems of nationwide concern, the reimbursable programs enable the Survey to apply its earth science expertise more directly to specific problems of Federal, State, and local agencies. The results of these investigations contribute in a very substantial way to the solution of urgent national resource problems and respond directly to the changing mutual needs of Federal, State, and local governments for earth science information.

Work done for the State, county, or municipal agencies may be performed on a cost-sharing basis. Funding arrangements may vary according to the type of investigation, and the Survey's annual appropriation act stipulates that Federal funds may not be used to finance more than one-half the cost of any topographic mapping or water resource investigation carried on in cooperation with a State or municipality. Within this general 50-percent limitation, each annual appropriation act also specifies the dollar amount of Federal funds that shall be available for cooperative water resource investigations. On the other hand, appropriated funds may be used to pay for more than 50 percent of the cost of other Survey cooperative programs. The activities jointly funded by State and local reimbursable program funds (State share) or direct program funds (Federal share) are collectively referred to as the Federal-State cooperative program. Other work done by the Survey for specific Federal agencies and non-Federal organizations is usually performed on a fully reimbursable basis.

Each of the five major organizational units of the Geological Survey named above is responsible for initiating and managing programs in its area of expertise, including basic research programs. Proposals for new research may be generated at any level within the Agency, from field to top management. All proposals are evaluated through

the management chain in systems specifically structured for this purpose. Similarly, review and evaluation of research progress are conducted annually. Priorities for research effort are founded on basic agency mission goals, and are tempered by congressional mandates, executive directives, cooperating agency needs, and feedback information from various review groups.

Most research supported by the Geological Survey is performed in-house, although some is contracted out to other Federal agencies, State and local agencies, private organizations, and academic institutions. The primary mechanism for ensuring the quality of contract research is the maintenance of in-house technical expertise.

Results of in-house research are subjected to exhaustive peer review, both in-house and out-of-house, to ensure the maintenance of high quality standards. Those results are ultimately published in one of the official book or map series of the Geological Survey, or in various technical journals worldwide. Authorship is attributed to individuals for all published results of research. Those results reported in technical journals are, of course, subject to discussion and review by readers of those journals.

Most researchers in the Geological Survey view the peer review system and the availability of high-quality outlets for publishing the results of one's research as an invaluable fringe benefit of employment with the Survey. The Geological Survey's publication policies, along with an international reputation for excellence in the earth sciences, are critical factors in attracting and retaining consistently high-quality researchers in the Geological Survey.

Various elements of Geological Survey research programs (in geology, hydrology, photogrammetry, land-use planning, and remote sensing of the Earth's environment) are regularly reviewed by standing or ad hoc committees composed of information users, such as other Federal agencies, State cooperators, educators, etc. Committee recommendations are incorporated into ongoing and future research efforts.

NATIONAL PARK SERVICE

Park Service Mission

On August 25, 1916, the Congress passed an act to establish a National Park Service; this act further underlined the legal enjoinder to retain the park system "in its natural condition." Specifically, the law provides that "the Service thus established shall promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified by such means and measures as conform to the fundamental purpose of the said parks, monuments and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."

Definition and Role of Basic Research

Basic research in the National Park Service (NPS) consists of those activities necessary to understand fundamental ecosystem processes. Such research relates almost exclusively to the legal mandate from the Congress of the United States, establishing the national parks and providing for "care and management of the same" in a manner that shall "provide for the preservation, from injury or spoliation, of all timber, mineral deposits, natural curiosities, or wonders within said park (Yellowstone Act of March 1, 1872), and their retention *in their natural condition*."

To our knowledge, the National Park Service and park system injunctions to manage the natural ecosystems in perpetuity are the only such mandates couched in law. To carry out these mandates requires a thorough scientific knowledge of basic ecosystem properties of the areas and of the factors that influence them.

Examples of Basic Research

Within the past 10 years, the most significant projects involving basic research carried out by or under the aegis of the National Park Service have dealt with the wolves of Isle Royale, Yellowstone elk, the bison of Yellowstone, grizzly bears, desert pupfish, sooty terns and wood ibis in the Everglades, Atlantic barrier islands, ecological diversity and stability in cave systems and investigations of cave radiation, urban ecology, social attitudes and interaction of park visitors, and a 51-part study of the South Florida environment.

A partial listing of these projects includes:

The Wolves of Isle Royale, L. David Mech, 1966, NPS Fauna Series #7.

Wolf Ecology and Prey Relationships on Isle Royale, Rolf Peterson, 1977, NPS Scientific Monograph Series #11.

Interagency Grizzly Bear Team Reports, Annual Reports for 1974, 1975, and 1976, NPS Miscellaneous Publications #8, 9, and 10.

The Northern Yellowstone Elk, Parts I and II: History and Demography, Douglas Houston, Research Report YELL/N/29B, Yellowstone National Park, 185 pp., April 1974.

The Northern Yellowstone Elk, Parts III and IV: Vegetation and Habitat Relations, Douglas Houston, Research Report YELL/N/29B, Yellowstone National Park, 444 pp., May 1976.

The Bison of Yellowstone National Park, Margaret M. Meagher, 1973, NPS Sci. Monog. #1.

National Cave Management Symposium Proceedings, James Quinlan, editor, Speleobooks, Albuquerque, N. M., 1977, 106 pp.

Ecology of the Barrier Islands, Cape Lookout, North Carolina, Paul J. and Melinda M. Godfrey, 160 pp., 1977, NPS Sci. Monog. #9.

Some Parallels Between Natural and Human Ecosystems, Dr. Theodore W. Sudia and Ed Hessler, in mss.

Man's Impact On the Outer Banks of North Carolina, Robert Dolan, 1972, and *Shore Zone Land Use and Land Cover, Central Atlantic Regional Ecological Test Site,* Robert Dolan et al., 1974, Nos. 3 and 8 respectively of the NPS Natural Resources Report series.

The Environment of South Florida, A Summary Report, Geological Survey Professional Paper 1011, 1976, 82 pp.

Current and Future Research Emphasis

Among the more interesting agency projects involving basic research in the national parks at the present time are the ongoing efforts to develop a valid urban ecology and inquiries into naturally occurring radionuclides in caves, grizzly bear ecology, and barrier island dynamics.

Research priorities for the next 3 and the next 10 years are the same, namely, to continue trying to understand the basic ecology of the national park system that the Service is mandated to perpetuate. High on the priority list in this regard is the assembling and continuous updating of retrievably stored basic resource inventories for all natural areas in the national park system.

Ethological studies of the major animal species occurring in the national parks (e.g., bears, goats, elk, moose, wolves, and birds) are among the promising areas of research not now supported but involving basic research and deserving of support.

Organization and Management of Research Activities

The Washington Office of the National Park Service is where policy formulation, analysis, and program evaluation occur. Regional offices are the operating arms of the Service. Research is carried out either by research scientists within the Park Service or through contracts with universities.

Research decisions emanate from resources management plans (RMP's) for each individual park area. RMP's are devised to carry out the intentions of the enabling acts for parks as described in each park's statement for management. RMP's are developed at the regional and/or park level.

Since by definition the National Park Service must engage in basic research in order to fulfill its legal mandate to manage parks in their natural condition, this thrust is best incorporated into the ongoing mission of the National Park Service by incorporating basic research into the execution of all RMP's, interpretation plans, and visitor use plans. Each of these action documents requires managerial approval, and subsequently all are used as programing documents for budgeting and funding.

Widely different criteria are used throughout the Service for initiating and terminating specific basic research projects, so no generality can be made in this area. In the National Park Service, basic research competes with operations for dollars, but this competition occurs during the initial budgeting process. To date, no basic research funds have ever been reallocated for any other purpose. The basic problem, however, remains: To obtain funding for basic research in the first place.

U.S. FISH AND WILDLIFE SERVICE

The Mission of the Fish and Wildlife Service

The mission of the Fish and Wildlife Service is to provide Federal leadership to conserve, protect, and enhance fish and wildlife and their habitat for the benefit of all people. It is dedicated to maintaining and improving the quality, abundance, productivity, and utilization of the Nation's fish and wildlife resources for the American people.

Since the Fish and Wildlife Service of the Department of the Interior is mission-oriented, the applied research projects associated with short-term practical needs are normally funded before longer term fundamental projects are considered. No distinction is made between applied or basic research other than its relationship to high priority needs. The Service operates under the program management system and its research activities tend to be heavily management-oriented and, therefore, are considered to be applied research.

Definition of Basic Research

In an attempt to arrive at a standard definition of basic research, Service research personnel were asked to develop an acceptable definition. Two general concepts emerged:

- Basic research is research that cannot be immediately applied.
- Basic research is research conducted at the discretion of the individual researcher in any subject area he selects.

A unanimously acceptable definition could not be developed, but for the purpose of this report the following definition was adopted: Basic research is that research the major objective of which is to increase knowledge without regard to specific management application of the results. Unfortunately, neither this definition nor any other the Service could develop allows a clear or consistent classification of its research efforts.

Role of Basic Research

The research effort of the Service in the past 10 years for both basic and applied has concentrated on studies to:

- Improve natural sport fish productivity
- Increase efficacy of production of hatchery fish
- Determine the effects of environmental contaminants on fish and wildlife resources
- Develop more effective methods of controlling damage caused by fish and wildlife populations
- Understand the ecology and fish populations of the Great Lakes to permit the best management of their fish populations
- Increase the stocks of certain anadromous fish species and protect others from extinction
- Increase our knowledge of threatened or endangered fish and wildlife and prevent their extinction
- Increase our knowledge of migratory birds and develop populations for the benefit of man
- Increase our knowledge of mammals and nonmigratory birds
- Evaluate the impact of man's activities on fish and wildlife populations and their habitat, and develop methods to reduce or mitigate their losses.

Examples of Basic Research

Some examples of interesting basic research in the wildlife area of research are studies on:

- The karyotipic variation in rodents
- The impact of sea otter predation upon invertebrate populations and the secondary impact of these prey species on the kelp beds
- The liver enzymes of blackbirds
- The environmental conditions that lead to the production of toxins by the Type C botulism organisms.

Organization and Management of Research Activities

Research priorities are established by program managers of the 17 programs of the Service. Each manager establishes the priorities of his program according to his needs and the goals of the Service. The Service does not contract research work to outside organizations unless it lacks the expertise, facilities, or other resources to conduct the work in-house.

Current and Future Research Emphasis

The Service's priorities over the next 3 to 10 years will relate to the studies noted above under "Role of Basic Research." Areas of research highlighted in the next few years are:

- Increased research on the effects of contaminants and their interaction on wildlife to protect the resource, whether as species, populations, or entire ecological communities.
- Increased research on the full impact on fish and wildlife resources and their habitat of water and related land resource projects conducted under Federal auspices or permits.
- Increased research on determining the environmental issues of critical importance to strengthen the capability of the Service to provide ecological information needed in connection with accelerated development of energy resources.
- Increased research on understanding the life histories of endangered species and factors that threaten the Nation's endangered flora and fauna and their ecosystems.
- Increased research on migratory birds, especially marine and coastal species, to identify both their species characteristics and those populations needing special protection or management considerations.
- Increased research on marine mammals such as the sea otter, polar bear, walrus, manatee, and dugong in relationship to their biological and management needs, distribution abundance, population status, and ecological relationships.
- Increased research on the evaluation of wildlife-caused damages and hazards and on the development of more humane, selective, effective, and safe animal damage control techniques.
- Increased research on the diseases of free-ranging populations of anadromous fish species, on the effects of environmental changes caused by man on these populations, and on the development of hatchery fish more capable of surviving in natural environments.
- Increased research on the Great Lakes and the determination of the effects of environmental contaminants on their fisheries.
- Increased research on the efficacy and safety of fish pesticides and drugs in order to reach full compliance with Public Law 92-516.
- A vital area of research which is now not adequately supported but could involve basic research and needs increased funding is research to determine the fundamental habitat requirements and population dynamics of a wide range of nongame fish and wildlife that is not now threatened or endangered.

OFFICE OF WATER RESEARCH AND TECHNOLOGY

The Office of Water Research and Technology (OWRT) makes no attempt to define basic research. Its mission requires only that research be problem-oriented. Basic research may be supported if it has potential to contribute to the solution of a water-related problem.

Examples of Basic Research

Listed below are the 10 most significant projects involving basic research (intramural and/or extramural) OWRT has carried out in the past 10 years:

Limestone Barriers to Neutralize Acidic Streams

In Pennsylvania, a project at the Pennsylvania State University has developed techniques for using crushed limestone to neutralize acidic waste streams. The research is applicable to both industrial waste discharges and to streams made acidic by mine drainage. The investigators responsible have been honored by the American Society of Civil Engineers for this accomplishment.

Irrigation of Citrus Fruit With Waste Water

The Florida citrus processing industry has found a solution to its waste water problems through a project conducted by the Florida Institute. This project demonstrated that the waste water can be used to irrigate citrus groves if certain precautions in the design and operation of the irrigation system are taken. The practice not only provides a quick and economical solution to the industry's waste water problem, but it can save millions of gallons of fresh water normally used for irrigation.

Application of Sewage Sludge to Farmland

Disposal of sewage sludge is a problem of great concern to urban areas. While the material is potentially valuable as a fertilizer and soil conditioner, its use is accompanied by the possibility of serious pollution hazards. In New York, a project in progress will measure and evaluate the environmental effects of applying liquid sludge to fields and farmland. It will also test the validity for up-

state New York of a proposed Environmental Protection Agency (EPA) formula for determining application rates, and its results will be useful in other regions having similar soil, terrain, and climate.

Disintegration of DDT

In New York, a research project has identified the initial processes in the disintegration of the DDT molecule. This will help in answering many questions relating to the environmental effects of this important insecticide and its future application.

Effects of Heated Waste on Estuarine Organisms

Study of the effects of releasing large quantities of heated waste water into a Maryland estuary showed that many important estuarine organisms, including those used as food by young striped bass, and species such as soft shell clams and white perch, suffered mortality when exposed to summer temperatures between 85 and 95 degrees F. Results of the study were used in establishing thermal loading limits in the official Maryland Water Quality Standards prepared in accordance with the Water Quality Act of 1965.

Improvement of Effluents From Oil Refineries

In Oklahoma, the first-year results of a study on toxic compounds in oil refinery effluents and their effects on aquatic biota were already being used in 1971 by oil refineries in the improvement of their effluent quality. This research is enabling the refineries to pinpoint the most lethal fractions of their plant effluents, possibly to the point that minor changes in a single portion of a refining process could make a significant reduction in the environmental impact of the refinery waste.

Reduction of Water Loss by Trees and Shrubs

A California investigator has worked with the California State Division of Highways to reduce water loss through transpiration from trees, shrubs, and other vegetation planted along the road for ornamental and soil-holding purposes. The research to facilitate development of antitranspirants has, in some test cases, shown a reduction in water loss of as much as 50 percent.

Ground-Water Quality Model

A ground-water quality model developed in California has proved to be a useful planning tool for assessing the effects of alternative water supply and disposal plans on the water in productive aquifers. The model has been applied in the Santa Clara-Calleguas area in testing alternative water management plans for Ventura County.

Effects of Highway Salt on Water Quality

In Maine, the use of excessive amounts of highway salt was causing loss of trees and contamination of wells. A research project led to the development of a different spreading technique that accomplishes the desired deicing effect with a reduction of up to 40 percent in salt usage. A simple, inexpensive metering device now monitors the flow of salt; this device resulted in savings of $500,000 in its first year of use.

Estimation of Consumptive Use by Crops

A project in Wyoming resulted in a report estimating the consumptive use of water by various crops grown in the State. The findings presented are used by the Wyoming Water Planning Office and by Federal agencies in estimating present and potential water demands during the planning of water resource development.

Current and Future Research Emphasis

The five most interesting agency projects involving basic research that are currently in progress include:

- Fundamental studies of desalination by freezing, by the Massachusetts Institute of Technology, Cambridge, Massachusetts. In this project, theoretical and experimental studies are being made on the kinetics and mechanisms of ice crystallization and of heat and mass transfer in ice crystallizers used in freeze-desalination processes. The project also includes fundamental studies of ice-melting and refrigerant recovery processes.
- A research program to examine fish behavior in response to hydraulic flow fields and to develop biological design criteria for proposed water diversions, by the University of California, Davis, California. Small fish are often killed or injured by entrainment or impingement at water diversion facilities. This one-year project is for the examination of the behavior of selected commercial and sport species of fish in various hydraulic fields in flumes under different levels of illumination. Results can be used to establish criteria for further fish protection at facilities in California and elsewhere.
- Aquacultural approaches to waste water nutrient recycling, by the University of Califor-

nia, Los Angeles, California. This research attempts to determine a compatible chain of organisms that can be cultured in a waste water nutrient base and that can link the sequential cultures into an integrated, economically viable system. Success of this research would make possible the stripping of nutrients from municipal waste waters and irrigation return flows while simultaneously producing animal species useful for human consumption.

- Quantification of nonpoint water pollutants from logging, cattle grazing, mining, and subdivision activities, by the Montana State University, Bozeman, Montana. The impacts of land use practices such as logging, cattle grazing, mining, and subdividing for development, with regard to the slow but persistent degradation of water quality that exists in almost every water body in the country, are being investigated in this research project. Results will be used to arrive at practical recommendations for minimizing adverse water quality impacts from nonpoint sources of pollution.
- Composite membranes for saline water conversion, UOP, Inc., San Diego, California. Investigators in the Fluid System Division, UOP, Inc., are working to perfect a new composite membrane for desalination of sea and brackish waters by reverse osmosis. This membrane, designated as PA-300, originated through basic polymer studies performed by several organizations for the Office of Saline Water of the Interior Department.

Research priorities for the next three years to support the Department's mission and current objectives include:

- Promoting water use efficiencies
- Protecting the water-based environment
- Improving water resources planning and management
- Solving energy-related problems involving water considerations
- Aiding in Indian self-determination through improved water development and management on reservations
- Research in support of saline water conversion.

Research to solve or mitigate other critical water-related problems of the States and regions of the Nation are determined largely through the "problem and research needs identification program" initiated in 1975 by OWRT in cooperation with State research institutes and leading water officials within the several States.

Research priorities for the next 10 years are:

- Water quantity problems, including control of excess water and water supply augmentation and conservation
- Water quality problems, including control of entering pollutants, effects of pollution, water treatment processes, and disposal of wastes
- Environmental impacts, including economic effects, ecosystem effects, and public welfare effects
- Water planning and management, including institutions, methods and procedures, and basic data.

Promising or vital areas of research not now supported but involving basic research that warrant increased emphasis and support by OWRT include new processes for water renovation or desalination and reuse of water from agricultural, municipal, and industrial wastes.

Organization and Management of Research Activities

Allotment of Funds to State Institutes

Title I, Section 100, of the Water Resources Research Act of 1964, as amended, provides for annual allotments of funds to a designated State university institute in each of the 50 States, Puerto Rico, the Virgin Islands, Guam, and the District of Columbia. These grants are for assistance in establishing and carrying on the work of competent and qualified water resources research institutes. The functions of these institutes are to conduct basic and/or practical water resource research investigations and experiments; to provide for the training of scientists through such activities; and to interpret and disseminate information about research results to persons who can use such information.

State institutes submit proposed programs to OWRT for review and approval pursuant to guidelines provided the institutes. In many cases, a State institute program will include projects to be carried out at two or more universities or colleges within the State. In this way, additional expertise and capabilities are made available to the State institute. It is OWRT's policy to encourage such multiuniversity cooperative programs.

Matching Grants to State Institutes

Title I, Section 101, of the Water Resources Research Act of 1964, as amended, provides for grants to the State institutes to match, on a dollar-for-dollar basis, funds made available to the institutes by State or other non-Federal sources. These funds are provided to help meet the expenses of specific water resources research projects that otherwise could not be undertaken. The State insti-

tutes and other universities and colleges in the State compete for these funds through the institutes by developing and submitting specific research proposals pursuant to OWRT guidelines provided the institutes.

Final selection of matching grant research proposals is made by OWRT. However, advice and recommendations received from the State directors are given careful consideration in this selection process. Most institutes employ a formal procedure, usually involving advisory committees, to select the most appropriate proposals for submission to OWRT. Each proposal is accompanied by a relevancy statement prepared by the director, and in many cases the proposals are ranked in the order that is most appropriate to the institute's research program. In the selection of projects by OWRT, regional distribution is considered, but when submissions from all institutes are weighed, the primary factors considered are the merit of the proposed research and the development of a compatible research program.

Saline Water Conversion Research

Under the saline water conversion program, projects selected may be funded through contracts or grants to universities, private industries, or other qualified research organizations. Unsolicited proposals are considered for all types of research, and proposals for development or engineering research may be solicited through established procedures. Projects are normally selected for support on the basis of scientific and technical merit, but cost becomes a consideration in the case of solicited procurements.

Research Management Processes

No research is conducted in agency laboratories. For extramural research, final decisions on award of grants and contracts are made by the Director of OWRT on the basis of recommendations by the scientific staff, outside reviewers, or any other group established to consider proposals and recommend selections.

OWRT has no specific commitment to basic research and is generally free to support research on the basis of merit. However, the role of basic research can be enhanced through illustrations of its value in developing useful projects. For example, basic studies sponsored by the Office of Saline Water led directly to development and commercialization of the reverse osmosis process. This process will make up a major portion of the Bureau of Reclamation's Yuma Desalting Project, which will provide 100 million gallons of fresh water per day for Mexico.

Research projects are usually selected from a group of unsolicited proposals, although occasional requests for proposals are published. In any case, the objective is to select projects on the basis of merit and relevance to some recognized problem area.

Under normal circumstances, an attempt is made to fund projects to completion or until some recognizable contribution has been made. Renewal of the project is declined if progress is not apparent.

During the initial phases of a project, funding is maintained at a level sufficient to demonstrate that progress can be made. Once progress is demonstrated, funding may be increased to achieve results within a shorter time.

Priorities for basic research must be established within the agency. OWRT has the requirement that all work have potential to contribute to the solution of a water-related problem. On this basis, basic and applied research compete for funds.

Within the saline water conversion program, which has a development activity, transfer of funds between research and development activities is limited by law. Reprogramming usually is permitted up to 10 percent of the authorized funds for a given fiscal year.

BUREAU OF RECLAMATION

Definition of Basic Research

Research is the process of seeking and discovering new facts, principles, and techniques, or applying them to new purposes. Simply put, it is prospecting for and utilizing new information. Research is often further delineated as "basic" or "applied," a distinction that is seldom completely clear. Within the framework of Bureau activities, to qualify as research (or development), the results must have application beyond a local area or a project feature.

Basic research, or fundamental research, is directed simply toward an increase in scientific knowledge, without necessarily a specific objective. In the Bureau, the amount of basic research is relatively small, and the investigations have identifiable objectives even though they are in the realm of unknown scientific facts or principles.

Role of Basic Research

The Bureau of Reclamation has no policies concerning support or nonsupport of basic research. For the most part, the Bureau's research is project-oriented, applied research, and funding is justified on that basis. However, the Bureau is free to fund basic research and has done so on a small scale over the years. Generally, it supports basic research only to the extent that its mission-oriented research activities incidentally have some basic research component.

Examples of Basic Research

Following are basic research projects carried out during the last 10 years:

- Electric power research. Dynamic characteristics of system loads and automation of power apparatus. (Research reports REC-ERC-73-18 and REC-ERC-76-17.)
- Evaporation reduction from reservoirs. (Research reports REC-ERC-72-23 and Stanford Institute evaluation report.)
- Vibratory compaction of cohesive soils. (Research report REC-OCE-70-28.)
- Corrosion of metals in concrete. (Research report ChE86.)
- A.c., d.c. circuit breaker research. (Research reports from Hughes Corporation.)
- Research on aquifers and aquifer drainage. (Research report REC-ERC-71-44.)
- Water quality related to stratified flow. (Research report REC-ERC-71-32.)

Additional research in the field of Atmospheric Water Resources Management (AWRM), which may have some component of basic research, includes: Colorado River Basin pilot project, Central Sierra research project, San Juan ecology project, Medicine Bow ecology project, Bridger project, North Cascades rapid-cloud catcher project, North Dakota pilot project, Florida area cumulus experiment, and High Plains cooperative experiment.

Current and Future Research Emphasis

Basic research projects currently in progress include continuation of electric power projects on dynamic characteristics of system loads and automation of power apparatus. AWRM projects that may include some components of basic research are the High Plains experiment and the Sierra cooperative pilot project.

For the next 3 to 10 years, priorities will be changing toward more research in environmental problems related to water resources development projects, and more research on energy-related problems, automation of power and water systems, and conservation of existing water supplies through more efficient use. In the AWRM program, high priority will be given to development of technology for management of winter orographic and summer convective precipitation.

In most areas of research the Bureau is currently covering all vital areas. In the AWRM project, areas in basic research that warrant increased emphasis and support include:

- Basic principles affecting downwind precipitation
- Basic principles relating precipitation to long period changes in the environment
- Basic principles relating to statistical evaluation of nonrandomized experiments, ice nucleation mechanisms, numerical methods used to simulate physical processes in multidimensional cloud system models, modeling of dynamical atmospheric processes, parameterization of physical processes in numerical models, short-term forecasting of precipitation and precipitation mechanisms, identification and use of predictor variables and covariants in experimental evaluation of precipitation modification experiments, and the effect of precipitation amount, timing, duration, distribution, and intensity on agricultural crop production.

Organization and Management of Research Activities

Research is initiated, reviewed, and evaluated by the Division of AWRM and the Division of General Research at the (E&R) Center and various branches, divisions, and offices in the Bureau's seven regions. Research is normally initiated by working level scientists and engineers who then submit a research proposal through normal chains of command for review, evaluation, and approval. A research review committee meets yearly to give general guidance and review of the Bureau's overall research programs. In the AWRM program, a yearly meeting of Bureau personnel and outside contractors and scientists is held to review the program.

Decisions are made on the basis of in-house capability to support the research. If this capability in terms of time or expertise is not available and if funds are available, research is performed by contract.

Normally, the Bureau does not explicitly recognize and incorporate basic research into the Bureau's program. If the research is in an area of great need and high priority, it stands a good chance of getting funded regardless of whether it is defined as basic or applied. The Bureau has little justification for funding a block of basic research separate from applied research.

DEPARTMENT OF JUSTICE

NATIONAL INSTITUTE OF LAW ENFORCEMENT AND CRIMINAL JUSTICE

Submitted by Blair G. Ewing, Acting Director

The Law Enforcement Assistance Administration (LEAA), a branch of the U.S. Department of Justice, was created in 1968 to provide financial and technical assistance to help States and localities improve their criminal justice systems. In the Omnibus Crime Control and Safe Streets Act of 1968, Congress made specific provision for a research institute within LEAA. The 1967 report of the President's Commission on Law Enforcement and Administration of Justice had identified research as an important priority, and Congress was concerned that law enforcement and criminal justice appeared unaffected by the scientific and technological progress that was improving other areas of American life.

Mission of the National Institute

To encourage research and development efforts in the criminal justice area and to assure that these efforts would be coordinated on a nationwide basis, Congress created the National Institute of Law Enforcement and Criminal Justice (NILECJ).

The Congress outlined these functions for the National Institute:

- To study and develop new approaches, techniques, and equipment for criminal justice
- To carry out behavioral research
- To evaluate criminal justice programs
- To collect and disseminate information
- To serve as a national and international clearinghouse for the exchange of criminal justice information
- To conduct training
- To survey criminal justice manpower and correctional facilities.

Definition of Basic Research

In differentiating between basic and applied research, the Institute generally has been guided by the definitions set forth by the National Science Foundation (NSF) in its annual survey of Federal research, development, and other scientific activities. These are:

- Basic research: The investigator is concerned primarily with gaining a fuller knowledge or understanding of the subject under study.
- Applied research: The investigator is primarily interested in practical use of the knowledge or understanding for the purpose of meeting a recognized need.

NSF further distinguishes these two types of research from development, which is defined as "the systematic use of the knowledge and understanding gained from research directed toward the production of useful materials, devices, systems, or methods, including design and the development of prototypes and processes."

Whatever the specific definition used, classifying discrete activities as either basic or applied research, or as development, is a judgmental process. It is relatively easy at the extremes of the research continuum, but much more difficult at the points of intersection.

The National Institute organizes its activities generally along the lines of the classic research, development, testing, evaluation, and marketing framework, and has congressionally mandated responsibilities in each phase of the sequence. Because the Institute is part of a mission agency, its primary activities are simultaneously directed at accumulating knowledge and at contributing to the development of action programs. Efforts designed

to accumulate knowledge generally involve basic and applied research; those aimed at developing action programs tend to fall at the applied research/development end of the spectrum. It is important to recognize, however, that although the manifest objectives of a single research project may be classified as either basic or applied or developmental, its latent objectives could appear in all three categories.

Role of Basic Research

As a research branch within a mission agency, the National Institute pursues both knowledge and action-oriented programs. LEAA action programs are developed within the context of an agencywide program development process, which explicitly recognizes that research and action activities need to be routinely linked so that, to the extent feasible and appropriate, action program considerations affect research priorities and, in turn, research and evaluation considerations influence action program priorities, design, and implementation.

At the same time, LEAA's action program development process recognizes that not all research leads immediately to practical application. Agency policy states:

> Criminal justice research is supported, in part, on the premise that the generation of new knowledge will lead to improved criminal justice practices. Not all research, however, is or should be supported with this objective in mind. A legitimate purpose of research is to develop knowledge that furthers our understanding of phenomena, whether or not that understanding has immediate or practical application.

In short, agency program development policies clearly envision a role for basic research. That role is reinforced by the congressional mandate to the Institute to "carry out programs of behavioral research designed to provide more accurate information on the causes of crime. . . ."

Examples of Basic Research

Criminal justice research as a discipline is only now coming into its own. A decade ago only a handful of scientists was engaged in criminal justice research. The available knowledge was scanty and fragmented. As the National Crime Commission put it, the greatest need was the "need to know." Thus the Institute in its initial years followed an exploratory approach, with emphasis on awarding "seed" grants to expand the number of researchers interested in crime and criminal justice.

Several programs from these early years began as basic or exploratory research efforts and now are in the process of being tested or demonstrated. One of the most notable is the Institute-sponsored work in crime prevention through environmental design.

Environmental design. In 1969, the Institute began a series of exploratory research studies that examined the relationship between the physical design of neighborhoods and buildings and citizen fear of and vulnerability to crime. Much of the research was done in public housing. The findings indicated that such design features as the height of buildings, the number of apartments sharing a common hallway, visibility in lobbies, positioning of entrances, and the layout of the building site affected both the rate of crime and the residents' perceptions of security.

The research also suggested that physical design could either encourage or discourage individual citizens to assume responsibility for protecting their rights and property. In short, the research revealed the potential for dealing with various aspects of the physical environment in ways that would increase protective activities by citizens. The major concept that emerged from the research was called "defensible space," which emphasizes a heightened sense of territorial concern and increased opportunity for casual, natural surveillance by residents.

The findings from this research were presented in a number of publications, including an Institute report, *Architectural Design for Crime Prevention;* a commercially published book by Oscar Newman, *Defensible Space;* and a publication by the Department of Housing and Urban Development, *Design Guides for Improving Residential Security.* More recently, the Institute has published *Design Guidelines for Creating Defensible Space* for use by architects, urban planners, and city managers in enhancing security in different types of housing.

Following the early research in public housing, efforts in the area of environmental design were expanded both in concept and scope. The emphasis has focused on developing comprehensive programs for preventing and controlling crime in various urban settings.

The pioneer research and demonstration efforts in this area coordinate three approaches for dealing with crime and fear:

- Physical and urban design
- Community organization and citizen action
- Law enforcement techniques.

Although each of these approaches had been

tried in some form, they had never been integrated and brought to bear in the same place at the same time. Equally important, the environmental design concepts are only now being applied at the scale of large urban districts with the size and complexity that characterizes most American cities where the crime problem is most severe.

Current efforts are devising a model planning and problem solving approach for dealing with urban crime within various kinds of neighborhoods. Through this research, a process is being developed that can be used to identify the crime problems within a neighborhood in terms of the interaction of physical and urban design factors, citizen behavior and response, and law enforcement practices and procedures.

The research has also highlighted a number of environmental conflicts that facilitate crime and has led to the development of possible strategies for dealing with these conflicts in various urban settings. One example of this approach is the development of a "neighborhood enclave" model, now being demonstrated in Hartford, Connecticut. This model employs access control, through such methods as restructuring interior streets as cul-de-sacs and the use of other physical barriers, to discourage entry and escape by intruders. Nonresidential traffic is channeled into preselected "through streets" where surveillance by both police and residents can be concentrated. To support the physical strategy, a number of community programs are being organized to promote neighborhood citizen action and to increase community cohesiveness. Special law enforcement techniques —such as neighborhood team policing—are being used in conjunction with the physical design and social action approaches.

Evaluation of the program will be completed early in 1978, and the results should produce valuable documentation of the effects of a comprehensive neighborhood crime control program.

The Institute currently is extending research and demonstration of crime prevention through environmental design to other urban settings—residential, commercial, and school environments. The goal is to develop and test broad design concepts to determine if they can effectively reduce crime and increase feelings of security among the persons who use these environments.

For example, attention is being given to several design concepts—such as access control and surveillance—as well as activity support. Both access control and surveillance involve the application of physical and psychological strategies to control the movement of criminals and increase their risk of apprehension. Activity support involves reinforcing existing or new community activities to make more effective use of the physical environment. Techniques for increasing community participation and social interaction are being explored.

The basic process involved in this expanded research effort includes the following key steps: (1) The identification of the crime problem in a specific environmental setting; (2) the design of a strategic crime prevention model that responds appropriately to the crime problem through the use of pertinent design concepts, including a set of coordinated and interrelated physical and urban design, social, and law enforcement strategies; (3) the adaptation of the model to a specific site (such as a school or commercial area) and the development of a set of interrelated design directives that identify the elements to be manipulated; and (4) the implementation and evaluation of the model.

The goal of the program is to determine the value and effectiveness of this approach to crime prevention. In addition, special attention will be given to disseminating the results obtained and the methods that have proved to be effective in carrying out the process of crime prevention through environmental design. In this way, the process can be institutionalized and used effectively by city planners, urban designers, and the law enforcement community. The process is also influenced by and valuable to community organizations and other groups interested in improving the quality of urban life.

Because work is still in progress, it is too early to say whether these environmental and nonenvironmental recommendations will prove successful. What is apparent, however, is that neighborhood renewal usually cannot be accomplished without attacking the crime problems; similarly, crime problems cannot be attacked without attempting neighborhood renewal: they should go hand-in-hand. If this view is borne out by the evaluation, then future efforts to alleviate inner city problems will require a coordinated effort involving a number of Federal agencies and perhaps others as well to focus simultaneously on such problems as crime, housing, and unemployment.

Methodology development. Another area of basic research, undertaken more recently, is examining research and evaluation methods with an eye toward developing more reliable, less costly tools for assessing the criminal justice system's performance and the impact of specific interventions. The science of evaluating social programs, particularly those in criminal justice, is still in its infancy, and new techniques must be explored for acquiring more accurate information and drawing more precise conclusions regarding program effects.

In evaluating the effects of new criminal justice strategies, a primary objective has been to determine their impact on the incidence of crime. But so little is presently known about how to quantify

the interrelationships between specific operations of the criminal justice system and crime incidence that most attempts to assess any program impact on crime have been open to serious challenge.

The analytic problem can be paraphrased quite simply: To measure the success of a crime intervention program, one must simply count the number of crimes that didn't happen because of the program. Of course, what this means is that one measures the difference between the observed crime rate in the target jurisdiction and some mathematical projection of the rate expected in the absence of the intervention. The degree of confidence in the result is obviously highly dependent on the confidence one has in the projection technique.

One example of an effort now underway to address this problem is the thorough and systematic exploration of stochastic modeling as applied to monthly crime rates. When thoroughly developed and validated, the technique should be able to detect with greater precision changes in the crime rate that result from programs or new approaches, distinquishing such changes from random month-to-month fluctuations and assessing the probability that observed deviations from projected rates are in fact statistically significant evidence of some change in the crime rate generating process.

The project evolved from a basic model that was developed and tested using police data from Atlanta covering a 52-month period. That project, undertaken as part of the local evaluation of the LEAA high impact anticrime program in Atlanta, demonstrated the feasibility of the analytic approach—time series analysis resulting in a model of the autoregressive, moving average type.

In the Atlanta model, 84 percent of the variance in the month-to-month distribution of serious crime could be "explained" by examining the structure of the distribution itself. For burglary alone this "forecasting efficiency" was 74 percent. Although there is no reason to suspect that Atlanta crime data are statistically distributed in any particularly fortunate way, it is obviously desirable to subject this assumption to empirical verification. Consequently, the basic model is now undergoing intensive validation through construction of similar models for approximately 15 cities.

Concurrently, developmental work is underway to extend the predictive power of the model and enhance its usefulness for criminal justice planning and evaluation. This work will investigate:

- The introduction of explanatory, socioeconomic variables into the model's structure
- Disaggregation to jurisdictions smaller than entire cities
- Integration of such disaggregated submodels to analyze crime displacement
- The applicability of these models to evaluation through the introduction of causal variables that reflect particular programs or strategies.

Methodologically, the assumption is that, by mathematical analysis of what has gone on in the past, a model can be developed for reliable prediction of the future, provided there is no change in any of the (unknown) processes whose dynamics are reflected in crime rate data.

The most primitive form of the model builds from the assumption that, in a given series of monthly crime rates, the variations and changes observed contain a component that is "caused" and a component that is truly random. The "caused" part may contain long-term trends (not necessarily linear) and seasonal variations, but no assumptions are made about the real nature of these underlying causes. The random component is, of course, constrained to have a zero average. Through analytic optimization and iteration techniques, a model is developed in the sense that an optimum form emerges which specifies not only the number and function of the necessary parameters but also their value. Predictions are then made as expected values. This means that the model's best estimate of the crime rate in any future month is projected to be made up of a component whose value is a relatively simple function of the crime rates in certain previous months (or their expected values) plus a random component, whose expected value is zero.

In addition to serving as the basis for the 15-city model, these data will be used to attempt to construct an aggregated model as a first step toward providing an analytic tool for projecting national crime rates. More important for this project will be the work designed to introduce causal variables into a dynamically more sophisticated version of the basic model. In essence, this will be done by examining relationships that might exist between different values taken on by the parameters that drive the individual city models and some of the city's socioeconomic characteristics.

Model building also will be attempted at a lower level of aggregation (census tract, police precinct) in selected cities in an attempt to establish the feasibility of the approach at this level and the potentially greatly enhanced utility such models might then have for planning and evaluation.

Research agreements program. Another basic research program was developed by the Institute in 1974. The research agreements program (RAP) links the Institute to selected universities and research organizations on a long-term basis. With funds from the Institute, these research bodies are conducting basic research in broad areas of crime and criminal justice, and their experience should

help to create national centers of expertise in a given program area.

Four research agreements have been in operation since FY 1975. The Rand Corporation is studying the characteristics of habitual criminal offenders and the treatment they receive in the criminal justice system. The Hoover Institution is applying econometric techniques to crime and criminal justice analysis, initially in examining the deterrent effect of punishment. Northwestern University is researching how individuals and groups in different urban locales perceive and respond to crime, and how information about crime is communicated. Yale University is concentrating on white collar crime, including studies of certain aspects of scandal and corruption and the regulation and control of white collar crime at the Federal level.

The habitual offender. The Rand research agreement is attempting to answer the following questions:

- How many habitual offenders are there?
- How much crime do they account for?
- Can they be identified?
- How effective is the criminal justice system in controlling the habitual offender?
- How can it be made more effective in the future?

During the past two years, Rand has undertaken seven separate studies to collect information. Some concentrate on habitual offender characteristics; others involve analysis of criminal justice system treatment of such offenders. Examples of some preliminary findings to date include:

- New sentencing policies should deal with those offenders who have been convicted at least once of a serious offense, but never sent to prison. This group accounts for a large proportion of self-reported felonies and felony arrests.
- Even those offenders who continue to be arrested after their young adult years show a decline in the frequency of their criminal acts.
- Within a group of offenders who can be characterized as habitual and dangerous by their prior conviction record, at least two different patterns of behavior can be distinguished: The intensive offenders, who are most dedicated to crime, commit more frequent offenses, and are more likely to avoid arrest and conviction; and the intermittent offenders, who commit crimes in a more sporadic and reckless fashion and are much more likely to be arrested.
- In California, the severity of the defendant's prior record is consistently related to more severe treatment by the system.
- Interviews with offenders have not suggested any means of intervening in the habitual offender's career short of incarceration. Most offenders attributed their continuation in crime to their own personal choice and not to external factors. Nevertheless, many were quite fatalistic about their possible return to prison in the future.

During the next two years, the work completed to date will be extended and refined to permit more precise policy evaluation. The continuation effort will involve: A study of approximately 3,000 offenders and four different criminal behavior patterns; a study of sentencing patterns in several States as they relate to the most serious offenders; and a study synthesizing current empirical data and developing policy models useful in estimating the impact of policy changes on crime, processing of offenders, and criminal justice system workloads.

Community reactions to crime. The Northwestern research agreement focuses on urban crime and the strategies developed by different neighborhoods to cope with crime problems. Research questions include:

- What are the variations in the ways communities organize and implement strategies to fight crime?
- What are the causes and conditions that determine how a community organizes to implement anticrime strategies?
- What is the impact on both the individual and the community of the ways in which communities organize to combat crime?
- What are the variations in individual perceptions of crime?
- What are the variations in the individual perceptions of crime and individual patterns of behavior?

The first two years of the Northwestern program have been spent conducting background work on reactions to crime and field research studies in 12 neighborhoods in 3 cities—Chicago, Philadelphia, and San Francisco. The Northwestern RAP also completed an extensive literature search on reactions to crime, including published and unpublished work as well as research in progress. A bibliographic essay integrating work to date and an annotated bibliography are now in preparation.

To summarize the state-of-the-art in the area of collective and individual responses to crime: This is a new field where concepts are still being clarified and measurement techniques refined. Much of the available literature is inconclusive and consists largely of sporadic, divergent research efforts.

Northwestern's background work also included secondary and comparative analyses of seven criminal justice evaluation studies: (1) The Kansas City preventive patrol experiment; (2) the COMSEC team policing effort in Cincinnati, Ohio;

(3) the Hartford, Connecticut, program in crime prevention through environmental design; (4) the Portland, Oregon, antiburglary program; (5) the San Diego field interrogation study; (6) an antiburglary program in Seattle, Washington; and (7) a police and urban services program in St. Petersburg, Florida. These studies were selected because they contained three or more of the following characteristics: (1) Attitudinal data on crime; (2) behavioral response data; (3) community focus; (4) victimization data; and (5) longitudinal data.

The secondary analyses effort will help clarify related work already completed, and will guide the RAP researchers in developing data collection instruments. A series of papers will be produced on such topics as dimensions of fear, the impact of the community on the individual's perception of crime, the relationship between the level of street traffic and fear of crime, and family composition and fear of crime.

White collar crime. The Yale research agreement focuses on white collar crime and the regulation and sanctioning of this type of criminal activity. The specific focus is the regulation and social control of white collar crime at the Federal level. The research includes: (1) An analysis of investigations initiated by the Securities and Exchange Commission; (2) a systematic examination of differences in the ways Federal prosecutors prosecute white collar crime versus other criminal cases; (3) an inquiry into the sentencing of white collar criminals by Federal district court judges; and (4) the impact of the sanctioning process on white collar criminals.

In addition to this core area of research, Yale has funded a number of individual studies related to corruption and scandal. These include: (1) A study of transnational bribery; (2) an economic analysis of corruption; and (3) an inquiry into misconduct in financial institutions.

The first two years of the program have been devoted to planning and support for small on-going individual research projects, including the three identified above. The planning activities included a state-of-the-art review of white collar crime, which examined critical issues identified by previous research. Yale's background work underlined the lack of conceptual development on white collar crime. Researchers have generally tried to group diverse criminal activities into a single category—white collar crime. Most past studies, however, have analyzed a single norm, law, type of business activity, or very homogeneous set of phenomena. Yale is attempting to conduct a series of related studies that will further the conceptual development of white collar crime rather than merely analyze a single law or activity.

Future efforts include: (1) Additional investigation of the Federal regulation of white collar crime, perhaps focusing on the Internal Revenue Service and a program agency such as the Department of Health, Education and Welfare; (2) an examination of how Federal agencies refer cases for criminal prosecution; (3) research on the perception of white collar crime (vs. other forms of illegality) by the public; and (4) exploratory work on the self-reporting of white collar crime.

Economic studies in criminal justice. Unlike the foregoing research agreements, which focus on aspects of or response to criminal behavior, the Hoover Institution RAP concentrates on a discipline—economics—and its applicability or potential applicability to crime and criminal justice problems. The question to be answered: How can the techniques and methodologies of economics and econometrics be brought to bear on crime and what relationship might these applications have for policy?

Hoover has established a Center for Econometric Studies of Crime and the Criminal Justice System. During its first year of operation, the center identified, acquired, and performed secondary analysis of all available data sources that could be useful to its researchers. The center also surveyed, collected, refined, and developed various models that could be applied to criminal justice problems.

The data are discouraging. At the aggregate level, existing data files—the FBI's Uniform Crime Reports, victimization surveys, California statistics, etc.—generally lack the required economic information. Even where it is available, however, the validity and reliability are questionable. On the individual level, a pilot attempt to collect such data proved extremely costly. Consequently, alternative methods for collecting such data are now being pursued.

In addition to extending research initiated in the first two years of this effort, Hoover will undertake a study in the drug control area. This work will investigate: (1) The effect of enforcement and treatment activities on the price of drugs; (2) the effect of change in the price of drugs on the consumption of drugs; and (3) the effect of changes in the price of drugs on the crime rate.

In addition to the ongoing research agreements described above, the Institute in 1977 awarded a grant to the Vera Institute of Justice for a major study of the relationship between employment and crime. The researchers will try to determine:

- Which types of offenders are deterred from crime by employment
- Which types of jobs are effective in curbing crime
- Which types of criminal activity are averted or reduced through employment.

The research will include secondary analysis of existing data bases, cohort studies of groups at

high risk of criminal activity, an archival study of criminal records of a group of unemployed persons, and evaluations of new programs aimed at reducing or averting crime through employment. If jobs with crime-deterrent potential can be identified, labor market studies will be conducted to determine current and potential availability of such employment.

Current and Future Research Emphasis

Eight years is a short time to develop a national research program in any field, but especially so in criminal justice, where few links existed between the research community and operating agencies. Nevertheless, there has been a steady accumulation of much-needed new knowledge in criminal justice research. With the acquisition of significant research results, the Institute, during the past year, has been engaged in the process of determining fruitful areas for further inquiry, identifying methodological problems that must be overcome, and highlighting areas where more basic or fundamental questions must be answered before we can move forward. Taken together, these considerations constitute both a set of criteria and a process for the careful selection of priorities for the future.

In selecting its research priorities, the Institute has given particular attention to wide-ranging consultation and careful review, including a survey of the Institute staff, consultation with Department of Justice and LEAA officials and with the Institute's 21-member Advisory Committee of distinguished researchers and practitioners. A tentative list of 10 broad topics was drawn up, reflecting the mandate of the Institute's enabling legislation and priorities set by the Attorney General. The topics are:

1. Correlates and determinants of criminal behavior
2. Deterrence
3. Community crime prevention
4. Violent crime and the violent offender
5. Career criminals and habitual offenders
6. Performance standards and measures for criminal justice
7. Management and utilization of police resources
8. Court management
9. Sentencing
10. Rehabilitation.

As this report is being written, reactions to the proposed long-range priorities are being gathered in a survey of 500 persons, including LEAA officials, State and local criminal justice planning agency staffs, academic and other researchers, and practitioners at all levels. The list also will have been reviewed by the Institute's Advisory Committee at its Fall 1977 meeting. It will be published in the National Institute's FY 1978 program plan.

The initial set of long-term priorities offers a stable framework for research—both basic and applied—over the next five years. At the same time, to ensure the flexibility needed for creative inquiry, the long-range agenda will be reviewed annually with the Institute's Advisory Committee so that it can be refined as needed.

The long-range agenda reflects the Institute's expanding involvement in basic research. For FY 1979, the Institute expects to maintain this pattern of growth in keeping with the President's expressed concern that Federal agencies assure an appropriate balance between basic and applied research.

Among the topics on the Institute's long-range agenda that will be the subject of basic research to begin in the current fiscal year are: "correlates and determinants of criminal behavior" and "performance standards and measures for criminal justice."

Criminal behavior. Crime is a complex phenomenon and must be viewed at several levels and from many different perspectives. Simplistic judgments that regard crime as a single entity or that accept without scrutiny apparent relationships between crime and such social conditions as poverty and broken homes ignore the reality: crime is multifaceted. To say that the crime rate is high in a particular locale fails to acknowledge the fact that not all crimes are committed at a high rate. The majority of the poor do not commit crimes; many persons from broken homes do not become criminals.

By collecting and analyzing more relevant information on offenders, it may be possible to define relationships between crime and other phenomena more clearly.

Research on criminal behavior will involve a number of disciplines and will deal not only with the characteristics of the offender—both biological and psychological—but those of the immediate and past environments; the characteristics of the crime; the availability of drugs, alcohol, and guns; the wider cultural climate; and whatever biases might be inherent in the law and legal processes.

Some of these facets of criminal behavior might be studied by gross statistical computation of crime rates with various demographic, ecological, educational, employment, and health indices. Because mere correlation does not necessarily imply causal relationship, however, other data must be gathered at the crime site and from the offender. The gross statistical correlates might be used in a "grounded research" way to suggest or corroborate individual and group tendencies.

Obviously, research of this nature is necessarily long-range and would require substantial funding over time. To launch this effort in FY 1978, the Institute has earmarked approximately $500,000, a modest sum that will support development of a precise agenda in this area and begin certain specific projects. If successful, such research should bring us closer to an understanding of criminal behavior and, in the long run, could suggest new methods for dealing with the crime problem. At the same time, the results might have implications beyond the criminal justice system to other aspects of American life.

Performance standards and measures. Criminal justice is a relatively new field of social science research, receiving major funding support only during the last decade. Because of the urgency of the criminal problem, measurement techniques were transferred from other areas of social science with little adaptation to the problem at hand, and measures were proposed and accepted with little inquiry into their ability to describe properly the phenomenon under study. The result has been a host of measures and measurement approaches and a dearth of substantiating information on their appropriateness and validity.

Among the principal research issues the Institute plans to address during the next few years are:

- What new measures and research methods can be brought to bear on criminal justice problems? Research in this area will explore the inadequacies of classical research designs and correlational methods in the criminal justice environment, which deal with elusive populations, behavioral extremes, and often rare events. Measures that focus upon population means in such phenomena may obscure key explanatory factors and issues for future research.
- What is known about measuring "traditional" performance in the criminal justice system? It is extremely difficult to measure the impact of an intervention strategy because of limitations in existing techniques to measure the performance of an agency in the absence of interventions. The two issues that must be addressed are the measurement of activities in operational agencies with respect to their self-imposed goals and the measurement of this performance as it pertains to something called a criminal justice system. These measurements are essential to enlightened policymaking and resource allocation.
- What statistics can be offered as standard measures of performance now? There are many statistics generated by law enforcement agencies and action programs. There is some evidence that practitioners want information on the performance of their activities. The research issue here is the identification of defensible performance measures that permit interagency and cross-program comparisons, and the acceptance of these measures in the field.

Organization and Management of Research Activities

Research Planning and Management

During FY 1977, the National Institute took a number of steps designed to improve the planning and management of research, particularly in the area of basic research. Among these was a new in-house research program. Although limited in scope, it provides an opportunity for Institute staff to maintain their research skills by conducting certain types of research projects. At the same time, it is expected to aid in recruiting talented individuals who may be interested in research management and the opportunity to participate in national research policymaking, but who are reluctant to divorce themselves entirely from research operations.

Under the in-house research program, staff members may perform relatively small research projects at the Institute, at a State or local government agency, or at a university, depending upon the nature of the research project. The kinds of research include: The design and implementation of an original research project emphasizing either policy-relevant or basic research issues; thorough reanalysis of major data sets produced by other researchers; comprehensive literature reviews and bibliographic essays that assess the knowledge base in a particular area; and the development and/or testing of methodological tools in criminal justice.

Other research management issues have been the subject of continuing study and refinement. To communicate its intentions to the research community, the National Institute publishes and disseminates a program plan at the beginning of each fiscal year. The plan briefly describes all Institute programs and projects and explains application procedures. In addition, the Institute last year expanded its use of individual program announcements that provide more detailed information on the background and objectives of specific programs, funding, and deadlines for submission of concept papers.

All concept papers submitted are reviewed initially by the Institute staff, who routinely solicit the views of one or more knowledgeable profes-

sionals outside the agency. To ensure quality control, all formal grant applications are reviewed by at least two experts from outside the agency. In some instances, three or more outside reviewers may be involved in evaluating the application.

In addition to this revolving peer-review system, the Institute also uses peer-review panels. The unsolicited research program, for example, augments the basic Institute program by providing support for the following types of projects:

- Small, individual research projects for which there are few alternative funding mechanisms
- Research projects with innovative approaches to criminal justice problems
- Research on interdisciplinary subject areas
- Exploratory studies in criminal justice areas in which there has been little previous work
- Research not currently identified as priority areas in NILECJ's program plan.

Each concept paper in this program is reviewed by one or more of the following peer-review panels: Courts, Corrections, Police and Advanced Technology, Community Crime Prevention, and Evaluation and Interdisciplinary Studies.

Organization of the National Institute

To ensure that fundamental research issues and needs are addressed in a systematic fashion, a limited reorganization was expected to go into effect with the beginning of FY 1978.

For FY 1978, the National Institute's total budget is $21 million, with approximately $12 million to be devoted to research and the remainder to evaluation, program development, training, testing, dissemination, and reference services. The work of the Institute will be conducted by the following offices:

Office of the Director. This Office has the authority and responsibility for providing national direction, control, and leadership to encourage research and development to improve and strengthen law enforcement and criminal justice at all levels of government. It directs and supervises the personnel, administration, and operation of the National Institute. The Director's Office also advises the LEAA Administrator on all matters pertaining to criminal justice research and development and makes recommendations to LEAA concerning research needs and priorities.

Office of the Deputy Director. This Office directs the preparation of analyses, plans, budgets, programs, and management policy and guidelines for the Institute. The Office is responsible for directing and coordinating all Institute activities in support of LEAA's action program development process, and for supervising the day-to-day management and administrative activities of the Institute.

Analysis, planning, and management staff. This staff provides analytic planning, and management support to the Office of the Deputy Director.

Office of Research Programs. This Office is responsible for the administration of the Institute's basic, applied, and developmental research activities primarily through an external grant/contract program. It also maintains a small, internal research program. Focusing upon the Institute's specified long-range research priorities and LEAA's applied program development needs, the Office formulates a balance of both basic and applied research that builds upon past efforts, develops new knowledge in priority areas, and contributes to LEAA's action program development process. The Office also administers the:

- Visiting fellowship program, under which researchers come to the Institute to execute research projects in the area of crime and criminal justice.
- Research agreements program, under which prominent research organizations may conduct a relatively extensive and long-term combined negotiated and self-initiated research endeavor in a particular area of crime or criminal justice.
- Unsolicited research program to encourage the submission of innovative, more basic, and high quality research studies that are not necessarily based upon Institute priorities or program needs.

Office of Research and Evaluation Methods. This Office is responsible for the administration of the Institute's methodological research and development activities primarily through an external grant/contract program. It also maintains a small, internal research program and provides other Institute and LEAA offices with advice concerning research and evaluation measurement problems associated with the Institute's long-range research agenda and on criminal justice systemwide research and evaluation problems. It develops more efficient and cost-effective methods for measuring the impact of program interventions and for addressing the evaluative needs of decisionmakers.

Office of Program Evaluation. This Office is responsible for evaluating selected programs primarily through an external grant/contract program. It also maintains a small internal capability. The Office evaluates selected national-level programs undertaken by LEAA; evaluates major criminal justice initiatives of State and local governments; and provides evaluative information on classes of programs and techniques both supportive of LEAA program development needs and the needs of State and local elected and criminal justice officials. The Office also shares responsibility with the Office of Development, Testing, and Dissemination (ODTD) for implementing and evaluating con-

trolled studies designed to test specific programs and techniques as part of LEAA's action program development process. The Office also administers the national evaluation program (NEP), which assesses the operation and impact of selected criminal justice programs and practices both in response to LEAA action program development needs and the evaluation requirements of the Crime Control Act of 1976.

Office of Development, Testing, and Dissemination. The primary responsibility of the Office is to assure that the results of research and evaluation undertaken by the several offices within the Institute are published and widely disseminated, and that all possible strategies for assuring that researchers, planners, practitioners, and officials within Federal, State, and local governments are aware of and can use research and evaluation results for both research and action purposes. The Office is responsible for implementing the Institute's research utilization policy and program through identification and development of program models; training; field testing; and reference, dissemination, and information services. It is also responsible for supporting the LEAA action program development process by: Providing input to the selection of agency priorities and program criteria; contributing to problem definition and selection of response strategy activities; developing program designs for tests and demonstrations; conducting operational tests and related training; providing refined design and site training for the demonstration phase of tested programs; advising on marketing strategies for successful demonstration programs; and providing supporting information services and document dissemination for all stages of program development.

DEPARTMENT OF LABOR

Submitted by Joan F. Anderson, Chief, Office of Technical Support, Assistant Secretary for Policy, Evaluation and Research

Labor Department Mission

The Department of Labor is charged, among other things, with administering and enforcing statutes designed to advance the public interest by promoting the welfare of the wage earners of the United States, improving their working conditions, and advancing their opportunities for profitable employment. In carrying out its mission, the Department performs a great deal of research and evaluation on relevant issues, with most of the research being of an applied nature rather than basic research.

There are two agencies within the Department of Labor that perform basic research, as they define it: the Labor-Management Services Administration (LMSA) and the Occupational Safety and Health Administration (OSHA).

Labor-Management Services Administration

LMSA administers three laws and major parts of an Executive order. It also provides assistance to collective bargaining negotiators and keeps the Secretary posted on developments in labor management disputes of national scope. LMSA provides technical assistance to State and local governments in matters concerning public employee labor-relations and pursues research and policy development in the overall labor-management relations field.

Basic research, as defined by LMSA, is systematic, intensive study directed toward fuller knowledge and understanding of labor-management relations and collective bargaining. The Office of Labor-Management Policy Development (LMPD) is specifically concerned with the laws the Assistant Secretary for Labor-Management Relations must administer, the legislation concerning labor-management relations and collective bargaining introduced into the Congress or State and local legislatures, and the development of new policy initiatives on labor-management relations and collective bargaining. LMPD supports basic research that relates to these operational objectives.

Among the most significant projects involving basic research carried out over the past 10 years are the following:

- Union trusteeships
- Union constitutions and the election of local union officers
- Exclusive union work referral systems in the building trades
- Financial and administrative characteristics of large local unions
- Collective bargaining in public employment and the merit system
- Selected earnings and demographic characteristics of union members, 1970
- Final offer arbitration in the public sector
- Labor-management relations in State and local governments, 1974
- Grievance and arbitration procedures in State and local agreements
- Public management's internal organizational response to the demands of collective bargaining in the 12 Midwestern States.

Among the most interesting items of study in their current program are the following:

- Changing structure of collective bargaining
- Collective bargaining in major industries in the United States
- Thesaurus for a computer information retrieval system on labor and industrial relations research
- The impact of union mergers on collective bargaining
- Current attempts to alter the bargaining structure in the construction industry.

Over the next three years, research priorities will be directed toward public employee labor relations, improving collective bargaining, and the means for resolving labor disputes. Over the next 10 years, research in broad terms will focus on the adoption of labor-management relations policies and strategies and union structure to major external stimuli (e.g., inflation, unemployment, the energy crisis, third-party interests), extra negotiating means of resolving labor-management problems not readily susceptible to collective bargaining settlement (e.g., the development of tripartite or bilateral industry committees and their impact on labor relations), and an assessment of union democracy after two decades of the Labor-Management Reporting and Disclosure Act of 1959.

Promising areas of research not now supported include an analysis of the nature of collective bar-

gaining and labor-management relations in non-profit organizations, the impact on American industrial relations of foreign-owned businesses in the United States, and the incidence and causes of voluntary changes in impasse procedures in Canadian federal employment.

The organizational structure for the conduct of scientific activities is as follows: An annual research workplan is initiated in the Division of Research and Analysis, and is reviewed, evaluated, and approved by the Office of Labor-Management Policy Development and then by the Assistant Secretary for Labor-Management Relations, with the review and evaluation assistance provided by staff of the Assistant Secretary for Policy, Evaluation and Research. The decision to conduct research in-house or on a contractual basis is made initially in the annual research workplan and justified there, subject to the review described above.

The mechanisms for the initiation and termination of basic research are the same as for applied research, namely the need for the research as set forth in the annual research workplan, described above. The level of support is determined at the initiation of the project and funds are obligated; they are not siphoned off to other projects. The priorities are established in the research workplan in terms of need for the project and reevaluated periodically during the fiscal year in terms of Department labor-management relations policy. This may change the priorities for research projects not yet initiated, but will not interfere with projects already started.

Occupational Safety and Health Administration

OSHA, established pursuant to the Occupational Safety and Health Act of 1970 (84 Stat. 1590), develops and promulgates occupational safety and health standards, develops and issues regulations, conducts investigations and inspections to determine the status of compliance with safety and health standards and regulations, and issues citations and proposed penalties for noncompliance with safety and health standards and regulations.

In general, OSHA conducts very little basic research. The agency couples research with an evaluation of existing operations.

As defined by OSHA, basic research involves the application of scientific principles to study phenomena related to the basic causes of injuries and illnesses and the environmental characteristics that seem to be related to safer and healthier workplaces. Basic research is done for the most part by OSHA's sister agency, the National Institute for Occupational Safety and Health (NIOSH). OSHA activities in basic research are limited to agency responsiveness and effectiveness in its enforcement activities. In the six years that OSHA has been in existence, no basic research has been initiated or completed; consequently, OSHA has no formal organization or management plan for basic research. Furthermore, NIOSH has the basic responsibility for a formal research plan. In the next three years, however, it is likely that some basic research will be performed, primarily in the area of causal studies on injuries and illnesses and characteristics of safe firms.

DEPARTMENT OF STATE

BUREAU OF OCEANS AND INTERNATIONAL ENVIRONMENTAL AND SCIENTIFIC AFFAIRS

Submitted by Oswald H. Ganley, Deputy Assistant Secretary

AGENCY FOR INTERNATIONAL DEVELOPMENT

Submitted by Curtis Farrar, Assistant Administrator for Technical Assistance

BUREAU OF OCEANS AND INTERNATIONAL ENVIRONMENTAL AND SCIENTIFIC AFFAIRS

State Department Mission

The overall mission of the Department of State is the conduct of the Nation's foreign affairs and the coordination of its foreign policy.

Definition of Basic Research

The Department has no official definition of basic research. The External Research Office of its Bureau of Intelligence and Research (INR) suggests the following distinctions among types of research:

1. *Applied research*
   a) *Policy research,* which identifies and weighs policy options and sometimes is used to make policy recommendations.
   b) *Policy-related research,* which is used to examine situations, forces, factors, trends, because they bear on identifiable instances of future policy choices.
2. *Basic research*
   Its purposes are to advance and order data, explanation, methods in fields of knowledge (the sciences and the humanities, disciplinary and multidisciplinary) which are selected because they illuminate matters that in the future will affect unspecified policy choices.

All research carried out by the Department at first hand is applied research. On March 10, 1977, the Bureau of Oceans and International Environmental and Scientific Affairs answered a request by the National Science Foundation, which requires data for its *Annual Survey of Federal Funds for Research, Development and Other Scientific Activities.* That survey lists no basic research expenditures for the Department in FY 1976. Applied research and development expenditures amounted to $1,611,000.

Role of Basic Research

Lack of internal basic research activity in no way implies a lack of concern. The Department supports secondarily, has a need for, and benefits from basic research. Its business—in addition to a close dependence upon progress in the social sciences—increasingly involves issues and policies inextricably associated with developments in the

natural sciences and technology, e.g., population, the environment, energy, geology, and oceans research. These and other aspects of science, whether at the basic or the applied research ends of the spectrum, have become important in foreign affairs. Indeed, the scope and import of Department requirements make the results of basic research a vital concern.

More precisely, in social science areas, the Department can benefit from essentially basic research in (1) the impact of modern cultural and educational systems, (2) causes of ethnic and cultural conflicts, and (3) major variables in attitudes toward perceptions about people of other cultures, religions, and nationalities.

In the recent past, academic research on foreign societies—once financed significantly by Ford and other foundations—no longer receives their considerable support. Also, universities, under severe financial constraints, have been forced to reduce their support of international studies and research. The Department of Health, Education and Welfare and the State Department have been preparing proposals for advanced foreign-affairs and foreign-areas research in universities which would be financed on the order of $10 million annually. Financing could be arranged under Department auspices if funds were made available while maintaining the autonomy of such research within university programs.

The Department does support outside basic research in several instances. One is its payment—in the present fiscal year amounting roughly to $1.7 million—to the North Atlantic Treaty Organization's (NATO) science program within its civilian budget. That program stresses fellowships, seminars, and cooperative projects among national members, all of which are oriented to basic science. Through science and technology agreements, such as those with Mexico, Brazil, Argentina, and Japan, it retains a stake in the successful pursuit of research and cooperation. The Department's concern is only partly political, because successful research and successful political relations in the science agreement framework go together.

In still another sense, the Department supports basic as well as applied science by facilitating the attendance of foreign scientists at international meetings in this country. It has developed exchange activities with the Soviet Union and with Eastern Europe. It also has supported the freedom of research in the oceans as it has been debated in the "Law of the Sea" negotiations. It seeks to facilitate the practice of science and research in the international setting.

The Department is both the beneficiary and the promoter of basic research. As beneficiary, it can profit greatly from increased activity and support of U.S. academic research in a variety of areas. At the least, the trend downward of academic research of value in foreign affairs must be arrested if the Department's mission is to be carried out efficiently. At the same time, increased support of research on an international basis will both assist its mission in the broadest sense and enable it to overcome more effectively the problems of foreign affairs and to pursue its programs.

AGENCY FOR INTERNATIONAL DEVELOPMENT

AID Mission

A major mission of the Agency for International Development (AID) is to provide technical assistance to developing countries with emphasis on the fields of agriculture, rural development, and nutrition; population planning and health; education and human resources development; and other special problems such as energy, environment, and intermediate technology.

Definition of Basic Research

Research for new knowledge and its application are vital to solving problems of the poor in developing countries. All AID research and development is oriented toward problem solving. In the conventional sense of seeking knowledge for its own sake without prior application goals, AID supports no basic research.

Role of Basic Research

Nevertheless, AID clearly recognizes the importance of a broad research and development program and its continuing dependence on both the Nation's fund of basic research and its extensive technology. AID encourages Federal support for continuing work in basic research as essential to the maintenance of the Nation's dynamic stock of basic knowledge.

AID has conducted an interregional research program since 1962, involving approximately $190 million for more than 270 research projects in a variety of fields, including agriculture, health, industry, economics, education, nutrition, population, and social development. The main purposes of the AID research program are: (1) To find solutions to technical and social problems that significantly impede progress in developing countries; (2) to add systematically to our knowledge of the forces and processes at work in the economic growth and social modernization of developing countries; (3) to explore and create improved technical materials for use in developing countries in collaboration with other assistance agencies; and (4) to increase the capabilities of recipient countries to solve their own problems.

Examples of Research

To achieve these applied objectives, it may occasionally be necessary to use highly sophisticated approaches which are considered by many to be research investigations into basic mechanisms, processes, and concepts. Some examples of such research investigations, both past and current include:

- Nitrogen fixation by bacterial action to reduce dependence on scarce nitrogen fertilizer resources
- Photosynthesis to increase the yield of agricultural crops
- Plant tissue culture under stress conditions to identify modified plant varieties for increased food production
- Agricultural and industrial waste utilization for food and energy and in waste control
- Agricultural economic base data, relationships, and mechanisms for policy guidance in controlling income distribution, family decisionmaking, rural development, and export development
- Immunological mechanisms underlying the development of malaria vaccine
- Physiological and medical side-effects of prostaglandin in fertility control
- Determinants of human fertility in terms of physiological, economic, and cultural factors
- Determinants of behavioral and attitudinal modification in nutritional, health, family planning, and cultural practices
- Nonformal educational mechanisms and evaluation capabilities in the development of self-help practices among illiterate adults and others beyond the formal school systems
- Economic investigation of theoretical, methodological, and empirical variables in contrasting cross-country conditions, relating both economic and social factors.

A number of specific activities bear on the significant role of research for developing country problem solving as follows:

International agricultural research centers. AID contributes to the support of nine international centers under the policy guidance of the Consultative Group on International Agricultural Research (CGIAR), a multidonor group for which the World Bank acts as secretariat.

Section 211(d) institutional grants program. This program provides support to selected academic and research institutions through five-year grants for the development of capabilities needed by the Agency in research, teaching, and consulting on problems of international development.

International training. Since 1941, approximately 177,000 foreign nationals have received training under the foreign assistance program in critical development fields.

African-American Scholars Council (AASC). The purpose of this project is to identify problems and conduct research related to African development needs through the individual and collaborative efforts of African and American scholars, thereby enchancing the research capabilities of the African higher education community.

Title XII famine prevention and freedom from hunger. This program provides for support to strengthen the capacities of the United States land grant and other eligible universities in program-related agricultural institutional development and research in developing countries.

AID sees a number of problem areas in which more attention to basic research would undoubtedly provide more critical knowledge, namely:

- Understanding of social, behavioral, and cultural dynamics involved in efforts to implement policy and program applications
- Approaches to facilitate greater participation by affected people in the identification, development, and institutionalization of problem-solving techniques for self-help
- Greater utilization of research findings through continuing, adaptive follow-through from the research stage to acceptable usage in local environments.

DEPARTMENT OF TRANSPORTATION

Submitted by William C. Steber, Deputy Assistant Secretary for Systems Engineering[1]

DOT Mission

The Department of Transportation (DOT) was established by an act of Congress in 1966 within the following statement of broad agency missions:

> ...establishment of a Department of Transportation is necessary in the public interest and to assure the coordinated, effective administration of the transportation programs of the Federal Government; to facilitate the development and improvement of coordinated transportation service, to be provided by private enterprise to the maximum extent feasible; to encourage cooperation of Federal, State, and local governments, carriers, labor, and other interested parties toward the achievement of national transportation objectives; to stimulate technological advances in transportation; to provide general leadership in the identification and solution of transportation problems; and to develop and recommend to the President and the Congress for approval national transportation policies and programs to accomplish these objectives with full and appropriate consideration of the needs of the public, users, carriers, industry, labor, and the national defense.[2]

From the above missions statement and from a general provision of the act that states the Secretary shall ". . . promote and undertake research and development relating to transportation, including noise abatement, with particular attention to aircraft noise; . . . " research and development goals and objectives of the Department have been refined. The dominant goal of departmental R&D is to provide the knowledge and technology needed to mold the various transportation modes—air, rail, highway, water, pipeline—into a balanced and integrated system. In this regard the following have been identified as the Department's R&D management objectives:

- Modernize regulations and legislation
- Minimize adverse impacts of energy constraints
- Improve safety and security
- Lessen unfavorable environmental impact
- Increase efficiency and service
- Increase knowledge base.

Definition of Basic Research

If basic research is defined to be fundamental research conducted solely for the purpose of understanding natural or social phenomena without regard to any potential applicability, then in that sense DOT does not support any basic research. The Department does, however, support research that is basic in a broader sense; the ensuing discussion is to be taken in the latter context.

Basic research at DOT is defined to be that research that is supportive of the overall mission of the Department but that is not targeted toward a specific application or a solution to a specific problem. This definition implies that the applicability of the research is potentially long range and broad in spectrum: Long range because it is not targeted to a specific immediate problem, and broad because the research can form a basis for diverse applications, thereby transcending strict modal boundaries.

Role of Basic Research

Basic research provides a body of knowledge that not only enables new applications but also illuminates or generates new alternatives to current procedures and methods. Thus, basic research in the economic and behavioral sciences may aid in the evaluation of policy alternatives, while technically oriented advanced research may make feasible new transportation systems now considered extremely costly or complex.

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[1] Additional information on DOT R&D is contained in the Appendix following this section.

[2] Public Law 89-670, 89th Congress, H.R. 15963, October 15, 1966.

Examples of Basic Research

An example of a basic technical research problem under this definition concerns advanced fixed-guideway systems. The range of potential applications of fixed-guideway systems is broad. In urban areas, potential applications run the gamut from circulation systems in high-density areas to high-speed arterial systems serving the major activity centers of a metropolitan region. In intercity transportation, the potential applications include high-speed passenger systems, freight systems, and multipurpose systems serving both passengers and freight.

Guideway and related costs would constitute a major component of any high-speed fixed guideway system currently conceived. Further, the relative merits and drawbacks of different vehicle/guideway concepts are far from being fully understood. Basic research in the various aspects of fixed guideway technology would form a body of knowledge from which to draw in planning specific systems in the future.

A second example of basic research at DOT is the research into advanced techniques for solving large-scale network flow problems. Large-scale networks are inherent in many transportation areas, including urban traffic planning and management, railroad route coverage, and future air network evolution. These areas share the difficulties in the manipulation and solution of large-scale network problems, and thus all would benefit from new ways to solve those problems. The mathematical aspects of large-scale network flow are complex, and new techniques would contribute to transportation theory as well as application.

The behavioral and economic sciences offer a third example: Research into the impacts of transportation upon the spatial distribution of economic and social activities, either regionally or nationally. Increased understanding of the relationships between transportation, spatial form, and quality of life can aid in evaluating alternatives which may significantly change transportation characteristics.

DOT also supports some basic research through its university research program, which was initiated about four years ago. DOT funds individual contracts with universities and other institutions of higher education for specific research projects proposed in response to general DOT solicitations for transportation-related research. While the number of contracts varies each year (147 funded in the 4-year history of the program), at least some involve research activities that can be classified as basic research.

Current and Future Research Emphasis

The above examples, drawn from the engineering, mathematical, and social sciences, illustrate the nature of transportation basic research and its potential role in support of the Department's various missions. However, these examples are not major research efforts. Because basic research forms only a small portion of the Department's total R&D activities and DOT does not conduct a continuous or systematic R&D program of basic research, there is no need to expand on areas of current or future research emphasis, other than the brief examples given above.

Organization and Management of Scientific Activities

Because DOT conducts very little basic research, the organization and management of such programs do not follow a rigid institutional framework or strict guidelines. Recognition and incorporation of basic research in mission agency programs must come from a commitment by agency heads, the Office of Management and Budget, and Congress that basic research programs are valid line items and not "strawmen" that can be cut in lean times. By its nature, basic research needs both a sense of continuity and a sustained commitment more than it requires any specific annual funding level.

The mechanism for initiation of basic research grows out of a formal review process by which the agency seeks to determine how it will meet its long-term objectives. Such a review inevitably leads to consideration of various options which in turn generate research requirements. At this point, priorities are established on the basis of greatest need and/or judgments on technical feasibility. Often, a "critical path" can be established if the research involves several intermediate steps. Cost-benefit analyses are seldom useful in establishing priorities for basic research.

Termination mechanisms should be built in to the initiation mechanism; that is, a set of criteria for the basic research should be established to enable a decision to be made on whether the research at a given point can move to development, or be reduced or cancelled. The Department uses a "hand-off" mechanism under which an advanced research project reaches a stage where it can be transferred to a modal agency. If the results of the research do not look promising, and further fund-

ing or effort does not seem warranted, the project is cancelled. In addition, if any of the milestones along the critical path are negative, decisions to alter or terminate the project can be made.

Ideally, the criteria used to determine a funding schedule for basic research projects are based on an estimate of the manpower and equipment required for the various program elements and the imposed project milestones. In reality, office budgets are considered as an entity rather than by line items, and specific program cuts must be made on an ad hoc basis.

APPENDIX TO DEPARTMENT OF TRANSPORTATION

Statement of William D. Owens, Acting Assistant Secretary for Systems Development and Technology, Department of Transportation, before the House Committee on Science and Technology, Subcommittee on Aviation, Transportation and Weather, Tuesday, March 15, 1977.

Mr. Chairman and Members of the Subcommittee:

I would like to thank you for the opportunity to appear before this committee to present an overview of the research development and demonstration (RD&D) program within the Department of Transportation. I have with me today Mr. William C. Steber, Deputy Assistant Secretary for Systems Engineering and Dr. James C. Costantino, Director of our Transportation Systems Center in Cambridge, Massachusetts, and Mr. Jerry Ward, Director of our Office of RD&D Policy.

Our presentation is in three parts:

1. First, I will address the process by which the Department manages the RD&D program with particular reference to the balance between near-term and far-term RD&D.
2. Second, Mr. Steber will highlight the RD&D program contained in the FY 1978 budget request, and finally
3. Dr. Costantino will describe some of the multimodal programs and advanced systems planning which is currently underway at the Transportation Systems Center in Cambridge and also will characterize the activities of other departmental field centers.

I would like to begin by discussing with you the design of the Department's management processes that are aimed at effective governance of the RD&D effort. In an important sense, this management issue is as significant (or maybe even more so) than the projects themselves, for it provides a way of getting a hand on the tiller that guides the future—or in the airman's parlance "flying in front of the power curve."

It is important to view the RD&D program of the Department in perspective with the total policy apparatus that governs the decisions and procedures within DOT. There must be an integration of our sense of the future with our ability to plan for it. The overall objective of the Department of Transportation is to enhance the quality of life of our citizens through consistent improvement in the varieties and mix of transportation alternatives. Our transportation systems move people and the goods they use, and consequently have impacts on nearly every facet of our lives. Transportation-related items account for 10 percent of our gross national product (GNP). If transportation purchases from other sections of the economy are included, the amount is 20 percent. In addition, 15 percent of our exports are transportation-related. Therefore, we must ensure that our transportation systems are economically sound, efficient, safe, meet our current needs, and are changing to meet our future needs.

The first area of focus for the Department's RD&D program is transportation technology, more generally thought of as *hardware*. In this area, we are concerned with improvements in our present systems and innovations which will allow for opportunities and choices in the future.

The second area concerns transportation *processes*. This RD&D requires an understanding of the complex relationships that exist in our transportation systems. Improvements in operational techniques and planning methodology are key elements.

It is important to emphasize that new technology, techniques, or knowledge have no impact on the transportation system until they are brought into actual use. The investments required in implementation and operation on a widespread scale exceed those in the RD&D phase by orders of magnitude.

The leadership role for DOT RD&D is a delicate one because of the diverse nature of the Department's constituents. These constituents include State and local governments and many industries (i.e., 200 railroads and supply firms, 170 organizations supporting the voluntary truck fuel economy program, etc.).

In the case of the Department's ground-oriented modes, it is these constituents who are the con-

sumers of the Department's RD&D product. Thus, technology deployment potential (or flow down) must be considered as carefully as the scientific excellence of the programs.

The job of eliciting guidance from our many constituents and then using the same constituents as conduits for technology flow down is a very complex and subtle process. We must translate complex techno-economic situations into understandable public discussion issues that can be treated by the marketplace. Some of the avenues which we use as forums for technology transfer are National Governors' Conference, National Conference of State Legislatures, National Association of Counties, U.S. Conference of Mayors, Urban Consortium, universities, and industry sectors including manufacturers and suppliers, and operations.

In the past, and we hope in the future, the prime mover in innovation and change in transportation has been and will continue to be the private sector. A prime goal of the Federal RD&D program is to maintain and increase the private sector involvement and to insure its support of and response to transportation needs.

The Federal role in RD&D becomes appropriate in a number of areas, particularly when the market mechanism is not able to respond to national imperatives. There are four major reasons for Federal involvement:

1. To support changing social requirements to which the market is not responsive. Safety regulation, mobility for the elderly and handicapped, and environmental considerations are some examples.
2. To respond to factors of national importance such as energy.
3. To become involved when the development risk and cost exceed the capability of the private sector. This is particularly true in support of the Department's operational responsibilities in the Federal Aviation Administration and the U.S. Coast Guard.
4. To stimulate the private sector for the needed investment in innovation when the market mechanism is not effective.

These four categories provide a means by which to judge the content of the Department's RD&D program.

A major consideration in the formulation of an RD&D program is the balance between near-term and far-term payoff—a question that has been treated in depth by this committee.

As this committee is aware, the required resources for an RD&D program increase significantly as one moves through the various phases of a development program. The definition of new concepts is far less expensive than hardware improvement or development. For this reason, it is to be expected that the preponderance of budget dollars will be dedicated to near-term programs. In addition, the present condition of our transportation system demands that we concentrate on major problems of immediate concern. Such important issues as the energy crisis, protection of the environment, failures in the railroad industry, and congestion in the cities, in addition to the need to improve safety, provide the focus for most of our near term RD&D dollars.

Advanced ideas are less expensive than big near-term projects—but far-term dollars have significantly more leverage on the future outcomes. Consequently, the premium on accurate planning perceptions of the future is extremely high.

I would now like to address the issue of future planning in somewhat more detail. We consider the identification of future opportunities in transportation to be one of our more important responsibilities and one that receives a substantial proportion of our attention.

It is not easy to think through how we would like to see the Nation's transportation system evolve in the future, or to formulate the RD&D strategies that will help carry us in the desired directions. It involves assumptions about an unknowable future. It requires a knowledge of our alternatives options and a reasonable understanding of the tradeoffs involved in selecting one over another. But, if we are to chart the directions for the technological and operational evolution of the transportation system, we must do our best to gain the required insights.

We have carried out a number of studies and analyses to help us in this important function. We have tried to look at transportation, not mode-by-mode, but in terms of urban, intercity, and freight transportation *mission* areas. We are interested in the relative roles and balance between the individual modes, and the potential for improvement in the overall system through better use, perhaps intermodal, of the individual elements.

This background of studies is providing us with a continually improving insight, and through interaction with the modal administrations, a growing consensus within the Department as to the best directions for RD&D. We have just completed, over the past six months, a series of meetings with the modal administrations in which we collectively reexamined and evaluated the major thrusts of the departmental program. This incidently is the groundwork needed for a zero-based budgeting approach for FY 1979.

In closing, I would like to share some of our thinking about the future climate for transportation improvements, as we move toward the year 2000. We believe the two primary factors that will mold this climate are the health of the economy and the

availability of energy. We think a successful transitioning of our energy system away from its heavy dependence on petroleum is not likely to be associated with a stagnating economy. Similarly a severe and protracted energy shortage is not likely to be associated with a continuation of the same growth in our economy that the Nation has enjoyed in the past. The possibility of inadequate energy supplies accompanied by a stagnant economy is a basis for our contingency RD&D planning, even though the development of major new systems is less likely than with a healthy economy. Our primary RD&D planning has been based on the assumption that the country will continue to experience at least a moderate rate of economic growth and will have adequate energy supplies, though at higher prices. This is the scenario which represents the greatest opportunities for desirable changes in our transportation systems.

We expect to generate roughly twice the total GNP between 1975 and 2000 than we did in the prior 25 years. In fact, in the next 25 years we are likely to generate a total output of $54 trillion, which is roughly equal to that of the whole prior century.

When we consider that in just the last 25 years, with a GNP of $27 trillion, we built the interstate system, the world's best air system, and can afford one car for every two persons, the oft-stated view that we can't afford anything very new or very large in the future may be overly pessimistic.

Between 1950 and 1975 GNP/capita grew from about $5000 per person to almost $7000 per person (all in 1975 dollars). If we have the same rate of economic growth in the future, GNP/capita will expand to nearly $12,000 by the year 2000.

Thus, it appears highly likely that we will be a more affluent population individually as well as collectively. We, therefore, think the Department's RD&D programs to provide us exciting options for this future are entirely appropriate.

Statement of William Steber, Deputy Assistant Secretary for Systems Engineering, Department of Transportation, before the House Committee on Science and Technology, Subcommittee on Aviation, Transportation and Weather, Tuesday, March 15, 1977.

Mr. Chairman and Members of the Subcommittee:

My name is William Steber. I am Deputy Assistant Secretary for Systems Engineering.

The process described by Mr. Owens has furnished the groundwork for the development and description of the key issues that must be addressed in our research development and demonstration (RD&D) program. That process is responsive to overall departmental goals and objectives and provides an opportunity for improving the productivity of our overall program by identifying significant RD&D program thrusts in the modes and at the Office of the Secretary of Transportation (OST). The key issues fall into three major categories:

Intermodal

Intermodal issues require action in more than one administration. By and large they result from looking at transport needs on a total system basis. The two most important areas are intercity freight and urban transportation.

Intercity freight encompasses a group of more specific actions concerned with efficiency and productivity in the movement of freight. All modes of transport (air, ground, water) become involved and interconnected when the total system approach is taken. Specific areas of concern are: The improvement of terminal facilities for multimodal use; flexible connectivity between the line haul and collection/distribution system; port planning, with special regard to container ports; special materials handling systems including energy; deepwater ports and related shore side connectivity; intermodal alternatives optimized for energy conservation; and shared freight/passenger systems.

Urban transportation is already the focus of much research and is particularly in need of intermodal total system integration. A major issue is the question of the balance between public transit and the auto as it relates to strategies for future RD&D. Planning research is being conducted by the Federal Highway Administration (FHWA) and the Urban Mass Transportation Administration (UMTA) on the nature of the needed sharing between highways and mass transit, taking into account the city and urban structure. Other areas of concern are terminals, intermodal connections and surface interconnecting links for satellite airports. FHWA, UMTA, the National Highway Traffic Safety Administration (NHTSA), and the Office of the Secretary are jointly working in this area.

Impacts

All modes of transport are influenced by the energy consumed, the need to provide for safe movement, and the pressures to minimize undesirable side effects caused by pollution and noise.

About half of the petroleum energy requirements for the United States is consumed by transportation. Our transportation system developed in an era when energy constraints were minimal. An examination of the present system with present energy costs and energy conservation in mind quickly reveals high cost, much inefficiency, and much energy waste as a result of this developmental history. It is imperative that conservation of

energy be a prime factor in emerging transportation R&D programs. In anticipation of the needed strong actions to realign our systems, a strong transportation energy program was developed in the Department in 1972, which has produced a substantial data base. This program produced the Motor Vehicle Goals report and other analyses which assisted the Congress in developing the fuel economy requirements in P.L. 94-163. Coupled with the energy conservation activities are the related engine emission considerations to insure the needed trade-off between conservation and pollution control. All modal administrations and the Office of the Secretary are heavily committed to transportation safety. Since the Federal role involves regulation, continuing research is needed for both passenger and freight systems in all modes to ensure practical, economically sound regulatory action.

Common Technologies

In four significant RD&D areas there is great commonality across the Department.

Construction. We have the most extensive transportation infrastructure of any country. That infrastructure is in place and functioning and at the same time it is continually growing older and deteriorating. Maintaining this enormous infrastructure at peak performance is largely a government function—whether local, State, or Federal—and is taking an increasing portion of the budget. Continued and expanded research is needed in all modes, but particularly the rail and highway modes, to seek long-term, cost-reducing solutions to this problem.

Automation. The rapidly advancing technologies of electronics and sensors will increasingly pervade all aspects of transportation: Automation, traffic flow control, navigation, communication, and information manipulation. The RD&D program is structured to capture the potential synergisms of applications in one mode to the problems of others. Flow augmentation through automated control systems can be a cost-effective alternative to more construction.

Navigation. Historically, marine, air, and now land navigation and positioning aids have been the responsibility of individual agencies of the Government such as the U.S. Coast Guard (USCG) and the Federal Aviation Administration (FAA). The rapidly increasing demand for accurate positioning and navigation on land, sea, and in the air points to the need for a coordinated program to provide the required service without unnecessary proliferation. The recently updated National Plan for Navigation will be a blueprint and first step in this direction.

Data. Underlying all of the modal and cross-modal problems is, of course, the information and data base needed to solve these problems. The heart of this information is hard data. Much of the Department's RD&D is focused in this data-gathering and analysis area and will continue to be an important element in understanding the tradeoffs involved in our decisionmaking process.

With these key issues in mind let me present a summary of the FY 1978 budget request, which illustrates the proposed funding distribution by organizational elements within the Department. The RD&D component funding levels range from nearly $23 million for the USCG to approximately $128 million for the FAA. Some of the principal RD&D areas within each DOT organizational element are identified below.

In the USCG and the FAA, the results of technical research are applied to the operating capability of each administration. The USCG program involving the marine transportation mode is directly related to its operating missions including search and rescue, aids to navigation, commercial vessel and recreational boating safety, marine environmental protection, port safety and security, and icebreaking technology. The Coast Guard is also pursuing a new broad program effort dealing with multioperational needs and energy conservation.

The FAA research program consists of efforts to improve the safety of the national air traffic control system and to progressively increase the capacity of that system to meet operational demands of the future. Aviation medical research to increase the effectiveness of traffic controllers and pilots is included in the safety efforts while an overall effort in the area of environmental protection is included within FAA's RD&D programs.

The FHWA program includes research in highway areas such as construction and maintenance, highway safety aspects, demonstration projects, and research for the Bureau of Motor Carrier Safety, all of which is directed toward improving safety and performance along the Nation's highways.

The NHTSA RD&D program meanwhile features motor vehicles and highway safety as well as improvement of accident investigating and data analysis. The overall program is responsive to requirements of the motor vehicle program and the traffic safety program of NHTSA with goals to curb the number of traffic accidents, injuries, and deaths. Another major NHTSA RD&D effort is in the area of fuel economy and the related development of vehicle energy regulation.

The Federal Railroad Administration conducts safety programs, socioeconomic assessment studies and research aimed at conventional rail problems. Emphasis is placed on greater applicability of research to the needs of users of RD&D results.

The UMTA program is conducted under Section 6 of the Urban Mass Transit Act. It consists of efforts to help urban areas meet their transporta-

tion needs in a manner consistent with national goals of clean air, energy efficiency, and mobility. In this vein, UMTA RD&D supports work to reduce life cycle costs and improve safety of conventional mass transit systems, to promote application of innovative new systems, and to provide general support of central city revitalization and accessibility for elderly and handicapped citizens.

The newly created Materials Transportation Bureau within DOT conducts research in the general area of hazardous materials and pipeline safety. Research focuses upon materials characteristics/properties to provide an expanded data base for improved safety standards, and advanced technology for improved materials transport safety.

A significant point regarding the composition of the Department's program with respect to resource allocation is that approximately three-fourths of total resources are in grants to others—the diverse constituencies mentioned earlier by Mr. Owens—while slightly less than one-quarter are devoted to operating activities, including RD&D. In FY 1978, 2.5 percent ($422 million) of the total DOT program level of $16.7 billion is slated for research and technology based efforts. Regarding the relative functional breakdown of the Department's RD&D program between improving DOT operational responsibilities (largely FAA and Coast Guard) and the systems options/regulations areas of technical involvement, both socioeconomic or "soft" research and more hardware or advanced prototype testing are conducted with a division that usually approximates an even share of financial effort.

I would like to address more specifically the proposed FY 1978 RD&D budget for the Office of the Secretary. *The transportation, planning, research, and development* appropriation, which has four subdivisions, finances those research activities and studies which directly support the Secretary's responsibilities and which can be more effectively or appropriately conducted in the Office of the Secretary than by the operating administrations within the Department.

Subdivision I, *policy and planning,* provides the foundation for development of transportation policy and coordination of national level transportation planning dealing with such issues as regulatory modernization, energy policy, allocation of Federal resources within the transportation sector viewed as a total system, and analysis of financially ailing transportation industries. This research is primarily socioeconomically oriented and is administered by the Office of the Assistant Secretary for Policy, Plans and International Affairs (PPI).

Subdivision II is the *program of university research.* This program has gained the interest and commitment of the most competent transportation-oriented academicians in the United States and provides an input to the Department of Transportation which cannot be obtained from any other source. The creative thinking and special expertise of the academic community provides a unique perspective to transportation research and a valuable reenforcement of the capabilities within DOT.

Subdivision III, *the systems development and technology* research category administered by Transportation Systems Development and Technology (TST) identifies and develops technical opportunities for improving transportation which are not appropriate for the operating administrations or the private sector. The foremost objective of this effort is to coordinate the diverse RD&D efforts of the Department into a total program which modernizes regulation and legislation, increases efficiency and service, improves safety and security, lessens unfavorable environmental impacts, minimizes adverse impacts of energy constraints, and increases the knowledge base.

The final OST RD&D subdivision is titled *special programs* and supports the work administered by the Office of the Assistant Secretary for Environment, Safety, and Consumer Affairs. Major efforts within the special programs category for FY 1978 include support for environmental affairs (specifically in the areas of improved environmental review/analysis process and coordination of handicapped and elderly activities within the Department), safety affairs, consumer affairs, facilitation efforts such as cargo and intermodal interface data, and finally transportation security.

I hope this overview of the FY 1978 DOT RD&D Program has given sufficient program content to enable you to move forward in your hearings with a general familiarity fostering an interactive exchange which will further promote our collective goal of improved transportation systems for the United States.

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

Submitted by James S. Kane, Deputy Assistant Administrator for Physical Research

Although it resprsents a modest fraction of the agency's total work, the basic research carried out by the Energy Research and Development Administration (ERDA) is a major enterprise. It is among the largest and most successful of such enterprises in the world. Much of it had its origins in the Atomic Energy Commission (AEC), and this history affects what is being done, who is doing it, and the philosophy underlying its conduct.

Most of the basic research is carried out by the ERDA national laboratories and by universities. The ERDA laboratories are in many ways unique in the Federal establishment. The majority are operated by universities and ties with the university community are close. The research traditions of American universities continue to mold laboratory approaches to problems and management styles. In these traditions, basic research is seen as a vital ingredient of the approach to solving national problems.

ERDA began its existence with the largest parts of its basic research enterprise in place. Many hundreds of contracts were in effect for research projects at university campuses. Many thousands of scientists were at work at separate institutions with unexcelled facilities and strong research traditions. The scientists at work in their laboratories represented an important national resource. The factual survey here is intended as an accounting of ERDA's stewardship of this resource and of the steps being taken to assure its healthy evolution.

The course of the evolution is not easy to foresee. New points of view are being introduced. The urgent need for attention to rapid commercialization of new energy technologies brings with it needs for industrial experience and approaches. The associated industrial research traditions are different from university traditions. Within the national laboratories, the intimate contact between developers and basic researchers shapes and invigorates both types of effort. On the other hand, the industrial firms carrying out ERDA-funded development and demonstration projects typically neither have nor seek funding for basic research tasks. The interactions are mostly quite indirect. The mechanisms for assuring the most fruitful level of interaction need strengthening.

The fact remains that ERDA is making a substantial commitment to basic research. Work of this nature must and will remain an important part of the functions that ERDA is carrying out.

ERDA's Mission

ERDA's activities are conveniently summarized in its name—energy research and development. The summary is generally accurate but can mean different things to different people. In common with other Federal departments and agencies, ERDA carries out a variety of functions extending beyond any obvious and simple interpretation of its central role. Its activities include, for example, building demonstration plants and stimulating commercialization of energy technologies. These are missions of the type commonly associated with the phrase "mission agency." Basic research is less often thought of as a mission. It seems worth exploring here to what extent and what types of basic research should be considered an ERDA mission.

The scope of activities for each Federal agency is determined by law. For ERDA, the principal laws defining its scope include the Energy Reorganization Act of 1974, and the Atomic Energy Act of 1954, as amended. Section 2 of the Energy Reorganization Act states that. . .

> ". . .it is necessary to establish an Energy Research and Development Administration to bring together and direct Federal activities relating to research and development on the various sources of energy, to increase efficiency and reliability in the use of energy, and to carry out the performance of other functions, including but not limited to the Atomic Energy Commission's military and production activities and its general basic research activities."

Section 3 of the Federal Nonnuclear Energy Research and Development Act includes the following language: "The Congress declares the purpose of this Act to be to establish and vigorously conduct a comprehensive, national program of basic and applied research and development." Section 31 of the Atomic Energy Act directs the Commission (which mandate was transferred to

the Administrator of ERDA) "to assist in the acquisition of an ever-expanding fund of theoretical and practical knowledge" concerning nuclear processes; the theory and production of atomic energy, including processes, materials, and devices related to such production; utilization of special nuclear material and radioactive material for medical, biological, agricultural, health, or military purposes; and the preservation and enhancement of a viable environment by developing more efficient methods to meet the Nation's energy needs.

The statutory language calling for basic research within ERDA is directive, rather than merely permissive. In this sense, basic research is clearly a mission of ERDA. The scope encompasses research related to meeting "the Nation's energy needs" whatever the energy source. The scope extends even further along the lines of responsibility carried forward from the AEC. The "general basic research activities" referred to in the Energy Reorganization Act may be taken to include the programs in high energy physics, nuclear physics, and general life sciences. These three programs are typically excluded from ERDA's summaries of its energy R&D. These programs are conducted, however, in concert with research more specifically focused on energy-related problems. Examples are given later of major contributions from high energy and nuclear physics research to development of new energy systems, and of the strong ties between life sciences and the assessment and control of environmental impacts.

The ERDA missions most directly related to energy technologies are spelled out in a great many provisions in the legislation assigning responsibilities to ERDA. In the "National Plan for Energy Research Development and Demonstration" issued by ERDA, these provisions are brought together and summarized in the form of eight national energy technology goals:

1. Expand the domestic supply of economically recoverable energy-producing raw materials.
2. Increase the use of essentially inexhaustible domestic energy resources.
3. Efficiently transform fuel resources into more desirable forms.
4. Increase the efficiency and reliability of the processes used in the energy conversion and delivery systems.
5. Transform consumption patterns to improve energy utilization.
6. Increase end-use efficiency.
7. Protect and enhance the general health, safety, welfare, and environment related to energy.
8. Perform basic and supporting research and technical services related to energy.

The scope of activities sometimes gives less insight into an agency's missions than the budgets developed during the authorization and appropriation processes. About 6 percent of ERDA's budget is allocated to its basic research programs, as the standard Federal definition of basic research is now used. The level is not set on a percentage basis. As discussed in the next section, the arbitrariness in the quoted percentage (or, at least, in its significance) is probably large.

Definition of Basic Research

Even within ERDA, different definitions of basic research are used in different contexts. The concept poses difficulties whenever the utility of expected results is a criterion for choosing research tasks. The National Science Foundation's (NSF) surveys on "Federal Funds for Research, Development, and Other Scientific Activities"[1] distinguish between basic and applied research on the basis of the primary motive of the individual investigator. Concern for fuller knowledge or understanding defines basic research. Concern for practical use in meeting a recognized need defines applied research. In ERDA, program managers typically base their judgments regarding priorities on the value of research in meeting the Nation's energy needs. The individual investigators know this and are also concerned, no matter how esoteric the research.

The ERDA reports for the NSF "Federal Funds" surveys thus incorporate difficult judgments. Consistency is hard to maintain. In FY 1977, the only research reported as basic was work supported by ERDA's Division of Physical Research. Even for much of this research, however, detailed and explicit consideration of its potential for meeting recognized needs determined which tasks were to be undertaken. Further, some of the research and development on particle accelerators was excluded, even though it is designed to enhance research classified as basic. The applied research reported by ERDA includes work supported by the Divisions of Biomedical and Environmental Research, Military Applications, Laser Fusion, and Magnetic Fusion Energy. This work regularly results in publications in leading scientific journals and is carried out by scientists recognized as leaders in their scientific disciplines. A part of the biomedical and environmental research, including much of the very fundamental research in the life sciences, has recently been identified as a separate program in the ERDA budget. Work in this program is being reported as basic research in FY 1978 for the "Federal Funds" survey.

[1] *Federal Funds for Research, Development, and Other Scientific Activities* surveys are prepared by the Division of Science Resources Studies of the National Science Foundation.

Somewhat different categories and definitions were used for an internal survey of ERDA research carried out during the summer of 1976. A category called "basic/fundamental research" was defined as "systematic study directed towards providing a broad base of information essential to understanding a wide class of mechanisms and phenomena." The operating costs associated with work assigned to this category were about 11 percent of the total for the agency's R&D programs. This "basic/fundamental research" is carried out by 11 ERDA divisions: the Divisions of High Energy and Nuclear Physics, Biomedical and Environmental Research, Basic Energy Sciences, Magnetic Fusion Energy, Solar Energy, Geothermal Energy, Materials and Exploratory Research (Fossil Energy), Laser Fusion, Military Applications, Electric Energy Systems, and Energy Storage.

This discussion of basic research in ERDA will cover work reported for the "Federal Funds" survey as well as that grouped under "basic/fundamental research" as defined in the internal ERDA survey. The general usage of the phrase "basic research" appears to extend beyond either of these survey definitions in, for example, articles and letters concerning the health of basic research in the United States. References to basic research are often best understood as including both directed and undirected research whenever the work is recognized as contributing to the advancement of a scientific discipline. A key indicator of such recognition is publication of the results in scientific journals. Such an indicator might provide a better match with the most widespread usages of the term "basic research," although no survey along these lines has been attempted within ERDA. With a definition modified in this way, more of ERDA's research would be classified as basic, particularly for studies in the physical sciences and mathematics related to military applications of nuclear energy and for studies related to the transport of pollutants and their effects on man.

Role of Basic Research

Using the current survey definitions, the principal ERDA basic research programs fall in the fields of general life sciences and physical research (the latter encompassing chemical and geosciences, materials sciences, mathematics, and physics). In the internal ERDA survey, these fields accounted for 93 percent of the basic research. The other 7 percent is the sum of the parts of various energy technology programs classed as basic or fundamental. For all the energy technology programs, the percentage of the effort classified as basic research averages less than 1 percent. The roles of basic research in ERDA depend, of course, on the nature of the program with which it is associated. For this discussion, the programs involving basic research will be considered in three groups: (1) Sustaining basic research, (2) technology-oriented basic research, and (3) special mission basic research.

In summary, the roles of basic research in ERDA can be described in terms of the nature of the programs carrying out the work. Part is organized under separately identified programs (basic energy sciences and general life sciences) designed to sustain and complement other approaches to energy R&D. Part is carried out within technology-oriented programs and is viewed primarily as an activity needed for getting specific jobs done. Part is carried out as a special basic research mission encompassing the Nation's principal efforts in high energy and nuclear physics.

Sustaining Basic Research

The sustaining basic research grouping provides an approach to meeting the Nation's energy needs firmly rooted in the disciplines of the physical and life sciences. The investigators in these programs look across their disciplines, seeking the research opportunities most significant for our country in dealing with its energy problems. ERDA program officials select the best of the ideas for support. In this way, the sustaining research complements the programs built around demonstration of specific energy technologies and control of their environmental impacts. Similarly, opportunities important to ERDA's national security programs are sought. In ERDA, the sustaining research is carried out under a program of physical research called "basic energy sciences," and under a subprogram called "general life sciences" within the biomedical and environmental research efforts.

These programs serve three general types of users: (1) Scientists and engineers in current applied research and development programs of the agency, (2) scientists and engineers outside the agency interested in solving energy-related problems, and (3) scientists and engineers who will be involved in the next generation of energy development efforts. The results, of course, are of interest to scientists everywhere interested in better understanding of natural processes.

The role is quite subtle as it relates to the current technology efforts. Basic research yields new information. Its utility is most often like that of leaves on a tree. The leaves are needed to sustain and expand the trunk. The lumber comes from many generations of leaves. It is impossible to say which single leaf is necessary for the growth of the tree, but the multiplicity of leaves is essential. Basic research yields more than increments of infor-

mation. It also provides new ways of grasping the possibilities and limitations of nature. Sometimes these attain the status of new fundamental laws. Perhaps more often they are simply mental constructs based on analogies or physical models. Using language borrowed from psychology, we can call these ways of grasping nature "new *gestalts.*" They account for most of the revolutionary impact basic research can have. They spread rapidly. They become an intellectual tool available throughout the scientific community. A significant new *gestalt* can affect applied R&D programs in ERDA very quickly.

The sustaining research programs play only a minor role in direct and immediate support of demonstration and control-oriented efforts within ERDA. The managers of the latter efforts need to design their programs around use of the present fund of scientific information and understanding. They need to set goals and milestones for themselves they can be confident in meeting. In most cases it would be impractical, as well as psychologically inconsistent, for them to try to fit into their schedules the information and discoveries being sought in basic research.

The need remains, however, for dealing with problems common to many energy technologies in a centralized way. In addition, ERDA needs to provide a suitable place for systems in their infancy that is separate from the harsh competition in demonstration-oriented programs. These two functions are becoming an increasingly important part of the basic energy sciences program, but should probably be considered as an applied research aspect of this program rather than an aspect of the basic research function within ERDA.

The role of basic energy sciences and general life sciences programs in meeting research requirements of groups outside the Federal Government—for example, of energy-related small businesses or of associations concerned with protection of the environment—warrants clearer recognition. The need is readily seen. Basic research concerning energy constitutes a long-term investment in national economic and technological resources. Although industry participation is encouraged, few private organizations can justify the high costs and economic risks associated with long-term research ventures. Therefore, the Federal Government must assume the major responsibility for supporting basic research in the national interest. The national interest here should not be considered simply derivative of other Federal activities. Ideally, these programs should seek to serve as a basic research arm for all organizations dealing with energy problems that are unable to support their own research. Contact with private organizations will ordinarily be made through universities and national laboratories, or, when the private groups include active scientists, through the scientific and patent literature. Direct commercialization of results from ERDA basic research has occurred fairly often, especially in the area of instrumentation. More often, the benefits accrue as the accumulated knowledge and understanding of detailed processes become part of the data on which applied technologies rest. Private organizations are served as they draw upon this data.

The central role for these programs remains that of providing resources to sustain and enhance the national energy R&D enterprise in the future. The primary audience will be the scientists and engineers working in that enterprise one and two decades from now. Thus, the general life sciences program conducts studies of damage, repair and molecular interactions in cells of man and various animal species in order to generalize the types of damage and repair and improve the bases for estimates of health hazards from the wide variety of common pollutants. The basic energy sciences program conducts studies of combustion to develop a detailed and precise understanding of combustion processes. The translation into improved environmental standards and commercial combustion processes takes time, perhaps many years.

The key step in implementing this central role is in the choice of scientific areas to pursue. The areas need to be relevant to the future course of energy development and demonstration. However, the individual research tasks may have no clear and apparent relationship to energy technology. The rhetoric of relevance can lead to damaging constraints. To avoid such damage, a clear conception is needed of the types of relevance appropriate for ERDA's basic research. Five types may be identified. Although the various types of relevance are not easily separable, they help throw light on the roles of the research and are described briefly below for this purpose.

- Type I relevance work is designed to produce immediately useful information or techniques—such as improved measurement of cross sections for nuclear reactions of importance to design of fusion energy systems or improved methods for screening chemicals for mutagenicity.
- Type II relevance work concerns systems or processes that are candidates for future direct application. Studies of an "artificial leaf" are an example, since the intent is to develop a method for capturing solar energy modeled closely on natural photosynthetic processes. Another example is the effort underway to develop model *in vitro* cell systems that retain the normal function of cells of key or critical organs and tissues.

- Type III relevance work involves developing deeper understanding of phenomena of known importance—such as hydrogen embrittlement of metals or the bases for extrapolating animal data to man.
- Type IV relevance work strives for advancement of a broad area of science judged likely to enhance the effectiveness of other parts of national energy R&D efforts. Examples include investigation of the basic structure and functions of key organ systems for which rapid cell replacement is required for body functions, or, in the physical sciences, studies of the reactive scattering of crossed molecular beams.
- Type V relevance work involves studies with the potential for modifying the structure of a discipline. The establishment (jointly with NSF) of a "national resource for computation in chemistry" may stimulate advances replacing current ways of thinking about chemical structure and reactivity. If this should happen, the relevance would not be confined to energy-associated concerns, but the importance to energy R&D would be pervasive and profound.

The basic energy sciences and general life sciences programs carry out research of each of these five types of relevance as illustrated by the examples cited. The balance among them is clearly an important consideration in program design. During ERDA's first two years, management attention has tended to focus on balance along a different dimension: the relationships with specific energy technologies. For work with types I, II, IV and V, analyses by energy technology have proved highly dissatisfying. The research with types I and II relevance can often be more appropriately classified as applied rather than basic. The bulk of it is carried out as an integral part of programs devoted to specific energy technologies and their environmental acceptability.

Technology-Oriented Basic Research

The group of efforts described earlier as technology-oriented basic research includes the variety of basic research embedded in ERDA's divisions concerned with energy technologies and national security. The role has special features for the most technically ambitious efforts, where practical objectives may be 20 years from full realization. Distinction between basic and applied research becomes especially difficult. ERDA's fusion energy programs illustrate the major characteristics of these types of efforts.

The Division of Laser Fusion is exploring methods for very rapid implosion of capsules containing the isotopes of hydrogen. Inertial confinement can lead to fusion of the nuclei and release of a large amount of energy. The role of the research in this program is simply to discover ways of getting the job done. It includes aggressive efforts related to new laser systems and to pellet design and fabrication.

The research seeking fusion by inertial confinement presses into uncharted areas of science. Where it helps chart new areas, it could be called fundamental. Presumably little or none of it meets the test imposed under the NSF "Federal Funds" definition of basic research, since the investigators are expected to keep applicability firmly in mind. ERDA also carries out studies concerned with fusion achieved by magnetic confinement. The program is substantially larger than the one concerned with inertial confinement. The goals are extremely demanding of scientific, as well as technological, sophistication. Our internal survey counted only 1.5 percent of the research under the Division of Magnetic Fusion Energy as basic. The point bearing on the role of basic research in ERDA is not one simply of semantic difficulties. The significant point is that a number of the tasks ERDA is pursuing have been viewed from their beginning as demanding pioneering research as an integral part of the approach to the task. This view strongly influences the weapons R&D efforts under ERDA's Division of Military Application (DMA).

Research funded by the DMA is carried out primarily at three major ERDA laboratories: Los Alamos Scientific Laboratory, Lawrence Livermore Laboratory, and Sandia Laboratories. The laboratory management is composed in large part of scientists who have done outstanding research in their own specialties. They are delegated substantial control over the mix between discipline- and project-oriented efforts, as well as primary responsibility for assuring close integration of these efforts at the working level. The research traditions are strong and elitist. The scope of the scientific efforts is broad. The staffs supported through DMA include many distinguished nuclear physicists, hydrodynamicists, astrophysicists, inorganic and physical chemists, metallurgists, ceramicists, and mathematicians. For perhaps a quarter of these staffs, the publication rate for articles in the open scientific literature is nearly the same as that for scientists funded under the basic energy sciences and general life sciences programs. Also, facilities provided by DMA and techniques developed under its sponsorship have frequently proved of great value for basic research in areas—such as biophysics—supported by other divisions. Our internal survey indicated that about 2.5 percent of DMA's weapons research, development, and testing efforts might be considered basic/fundamental research but, using the NSF defi-

nitions, none of these efforts could be counted as basic research for the "Federal Funds" survey.

The traditions—and the competing demands—give research a less prominent role in many of ERDA's energy technology programs. The primary tasks during ERDA's short existence have been to get demonstration projects underway with a view to minimizing the time for commercialization. A substantial number of individual basic research efforts have nevertheless been started by the Divisions of Solar Energy, Geothermal Energy, Electric Energy Systems, and Energy Storage. For the most part, this research, although fundamental in character, is expected to yield information or techniques immediately useful in other aspects of a division's work. Some of the research under the solar electric program provides an exception; fundamental work is underway on the major classes of materials suitable for solar cells, and on the determinants of device and system parameters.

Somewhat different considerations apply to the basic research under the Assistant Administrator for Fossil Energy. The basic research is carried out as part of the activities of the separate Division of Materials and Exploratory Research. In addition to its function of supplying new information and techniques, the basic research serves to strengthen the institutional capabilities of ERDA's Energy Research Centers (where small but distinguished basic research efforts were started many years ago under the Department of the Interior). Also, important ties are provided between fossil energy programs and the academic community through programs of grants to individual university investigators.

Special Mission Basic Research

The role of ERDA's high energy physics program and nuclear physics program differs in a fundamental way from the roles of the other ERDA basic research efforts. The work can be viewed as special mission research, or, in other words, as research needed to meet responsibilities assigned to ERDA that stand somewhat apart from the main body of ERDA responsibilities. The basic research, in itself, is the mission. The interactions with other ERDA programs are important, but they determine neither the magnitude nor the directions of the principal efforts.

These programs seek deeper understanding of some of the most fundamental aspects of the behavior of energy and matter. The experiments are centered around accelerators. High energy physics deals with elementary particles—their creation, their transformations, and the forces and other relationships among them. The overall goal is to uncover the fundamental physical laws that reveal themselves at very high energies. Nuclear physics deals with nuclear processes and structure. In ERDA, the nuclear physics program is defined to include the areas known as heavy ion physics and medium energy physics; nuclear research at lower energies retains strong ties with current applications of nuclear energy and is conducted as part of the basic energy sciences program described earlier.

In FY 1978, ERDA has budgeted for outlays of about $320 million for its high energy physics and nuclear physics programs. These are among the largest efforts in the physical sciences in the United States. The expenditures are similar in magnitude, however, to those used for a single laboratory in Western Europe, CERN, which is operated by the European Organization for Nuclear Research and carries out work in these same fields. In the internal ERDA research survey mentioned earlier, these programs accounted for about 50 percent of the operating costs devoted to basic research.

Progress in these fields depends sharply on the design, construction, and improvement of major experimental facilities. Over the past 15 years, construction costs have averaged about one-fifth of total program costs. The high energy physics experiments are centered around four major accelerators—the 500 GeV proton synchrotron at the Fermi National Accelerator Laboratory, the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory, the two-mile-long electron accelerator at the Stanford Linear Accelerator Center (SLAC), and the Zero Gradient Synchrotron (ZGS) at Argonne National Laboratory. Construction is underway for a major new facility at SLAC which will provide for experiments of unprecedented power using colliding beams of electrons and positrons. A design has been developed for a new facility providing colliding proton beams and using the AGS at Brookhaven National Laboratory as an injector. Closedown of the ZGS at Argonne is scheduled over the next several years. The major facilities used in ERDA's nuclear physics program include the Anderson Meson Physics Facility at the Los Alamos Scientific Laboratory, the Bates Electron Accelerator at the Massachusetts Institute of Technology, a linear accelerator for heavy ions (known as Super HILAC) and a synchrotron at Lawrence Berkeley Laboratory, and several cyclotrons and Van de Graaff accelerators. A major new facility, the Holifield Heavy Ion Research Facility, is under construction at Oak Ridge National Laboratory. ERDA support for a large number of less powerful nuclear physics facilities located on university campuses has been terminated over the last several years.

ERDA's high energy physics and nuclear physics programs continue the lines of scientific inquiry that led to the current applications of nuclear ener-

gy. They have long been seen as a natural part of energy research. Their relevance to other aspects of energy R&D is primarily of the sort described earlier as Type V. They deal with the kind of fundamental issues whose resolution is likely to restructure our ways of thinking about the physical world. Such restructuring, if it does occur, will affect all the physical sciences. And if history is a valid guide here, the social consequences are likely to be of great importance.

The day-to-day interactions with workers in other ERDA programs revolve around the technologies used and developed in the high energy and nuclear physics programs. Accelerator technology vitalizes these programs. Its advancement requires a major part of their resources. It is impressively developed in many ways rather like the technologies of internal combustion engines and aircraft. As accelerator technology has flowered, the applications have multiplied. Accelerators and accelerator technologies are widely used in materials research and various aspects of research in chemistry, and, for that matter, increasingly in electronics technologies and clinical medicine. High efficiencies can be achieved. As much as 50 percent of the total energy for operation of an accelerator can be converted to the kinetic energy of a well-defined beam of ionized particles. In the past several years, two promising direct applications to energy production have been identified and early studies and design work are underway in the high energy and nuclear physics programs. The first of these involves acceleration of heavy ions for implosion of fusion targets and is being carried out jointly with the Division of Laser Fusion. The second, known as accelerator production of fissile materials, involves breaking up heavy nuclei in solid targets to give neutrons and other fragments, then capturing the neutrons to generate new fuel for fission reactors (much as is done in breeder reactors).

The high energy and nuclear physics efforts for many years have included pioneering work in the design and construction of large superconducting magnets. Many of the people drawn from these programs now have key positions in the other ERDA efforts concerned with the technology of superconductors, such as superconducting power lines and superconducting magnets for magnetohydrodynamics and fusion power. High energy physicists have also pioneered development of computer-based systems for pattern recognition. Such systems are essential for interpretation of the large number of photographs from the particle detectors known as bubble chambers. The systems have proved readily adaptable to other applications, such as analyses connected with regional environmental planning and recognition of defective chromosomes. A number of examples have been cited here to illustrate the range of interactions of the high energy and nuclear physics programs with other matters of importance to ERDA. In practice, the role of these programs in ERDA extends well beyond that of carrying out their particular special mission.

The special mission research in ERDA derived from the AEC is not confined to high energy and nuclear physics. Two fairly sizable activities within the basic energy sciences program should probably also be viewed in this light. This program operates research reactors that are copious sources of neutrons used to probe and elucidate the internal structure of materials. One of these reactors, the High Flux Isotope Reactor at Oak Ridge National Laboratory, was designed as the Nation's principal source of transplutonium elements for research purposes. The levels of effort devoted to studies of materials by neutron-scattering techniques and to production of transplutonium elements for research are strongly influenced by the uniqueness and national importance of the ERDA facilities. The same considerations apply to the use of a set of electromagnetic separators at Oak Ridge for production of separated isotopes. Much of the other special mission research in ERDA is applied research. It includes programs devoted to medical applications and to space applications of nuclear technology.

Examples of Basic Research

The ERDA programs that include basic research have been identified in the course of the discussion of the roles of basic research in ERDA and a variety of examples have been given of specific research tasks. In this section, the full scope of the research will be briefly defined for each of these programs. The total operating costs estimated for fiscal year 1978 are used as a measure of program size. Under ERDA's budgeting system, these costs exclude those for capital equipment and construction of new facilities. For the programs carrying out research described earlier as technology-oriented, the total operating costs are dominated by expenditures for applied research, technology development, and demonstration projects.

The interfaces among these programs are complex and often critically important to ERDA's effectiveness. Coordination among the programs demands strong and continuing attention. A variety of mechanisms are used. A number of interfacial areas are covered by formal staff coordinating committees such as in the areas of materials, combustion research, and nuclear data. Workshops

and topical meetings are arranged frequently. Perhaps even more important than the formal mechanisms are the daily interactions of people in the program divisions, in the laboratories, and in the universities.

High energy physics (FY 1978 operating costs, $186 million). The program scope encompasses research into all aspects of elementary particle phenomena, including theoretical and experimental study of the fundamental structure and transformations of matter and energy. Accelerators and related experimental facilities are operated for the use of university and ERDA laboratory scientists in conducting high energy physics experiments. New accelerator concepts and technology are developed and new facilities are designed. New experimental techniques and detection devices are developed. The program includes about 90 percent of the total U.S. national effort in the field of high energy physics.

Nuclear physics (FY 1978 operating costs, $66 million). This program covers experimental and theoretical studies of atomic nuclei, using probes available from medium energy and heavy ion accelerator facilities. The studies seek improved understanding of nuclear matter. They deal with the forces, symmetries, and conservation laws determining nuclear properties and dynamics. The program substructure consists of three major elements: Medium energy physics, heavy ion physics, and nuclear theory. Medium energy physics in this context is taken to mean studies of nuclear interactions of ions of mass less than 5 and with energies above the pion production threshold, but less than 6 GeV. Heavy ion physics is taken to mean studies of nuclear interactions of accelerated ions whose mass is 5 or greater.

Inertial confinement fusion (FY 1978 operating costs, $105 million). Areas of research in this program include systems studies and applications, diagnostics development, electron beam systems research and development, Nd: glass laser development, CO_2 laser system development, new laser systems research and development, pellet design and fabrication, and target interaction experiments. All of the research is considered applicable to the program objectives.

Weapons research, development, and testing (FY 1978 operating costs, $594 million). Areas of research and technology development (RD&T) in this program include nuclear weapons development, nuclear design technology, nonnuclear design technology, fabrication and metrology, testing and facility technologies, computational science, materials research and development, physical processes in nuclear explosives, and other supporting research relevant to weapons sciences. The last four of these areas have sometimes been identified as including some basic or fundamental research. About 2.5 percent of the total RD&T operating program might be considered to fall in the basic research category. As noted earlier, work under this program results in a great many publications in major scientific journals. The following are typical of the subjects and disciplines reflected in these publications: Energy transport, explosion research, atomic physics, behavior of materials at high temperatures, transition element chemistry, low temperature physics, geodynamics, atmospheric physics, astrophysics, nondestructive testing, nuclear physics, measurement standards, hydrodynamics, particle transport, radiation flow, high pressure equations-of-state, neutron cross sections, composites, surface metallurgy and film deposition, polymers, ceramics, glass and glass ceramics, analytical techniques, numerical analysis, mathematical physics, statistics, image analysis and enhancement, symbolic and algebraic manipulation, programing languages, and multidimensional codes.

Geothermal energy (FY 1978 operating costs, $94 million). Areas of research and technology development in this program include geothermal drilling technology, power conversion systems for geothermal applications, heat exchangers and rejection systems, management of geothermal brines, geothermal reservoir assessment and confirmation, environmental control for geothermal systems, extraction technology, and materials development and corrosion studies. The last two areas are identified as including basic or fundamental research. About 2 percent of the total program is considered basic research.

Magnetic fusion energy (FY 1978 operating costs, $200 million). Areas of research and technology development in this program include atomic, molecular, and nuclear data; plasma theory; computational plasma research; plasma physics data and diagnostics; plasma engineering; superconducting magnets; energy storage; and fusion reactor materials. Only the last of these is identified as including basic or fundamental research, so that about 1.5 percent of the total program falls in a basic research category. The program clearly includes much of the Nation's pioneering research in plasma physics, but, in the context of the program objectives, this research is classed as applied.

Solar energy development (FY 1978 operating costs, $231 million). ERDA's solar energy activities feature programs dealing with each major avenue for use of this energy source: Photovoltaic energy conversion, ocean thermal energy conversion, fuels from biomass, environmental and resource assessment, solar heating and cooling of buildings, solar thermal electric conversion, agricultural and industrial process heat, wind energy conversion,

and technology transfer and commercialization. About 5 percent of the total solar energy development efforts have been identified as basic or fundamental research. Of the nine programs listed here, all except the last four include some basic research.

- The photovoltaic energy conversion program covers the following areas of research and technology development: III-V materials (e.g., gallium arsenide) and solar cells; ternary, quaternary, and other materials and solar cells; system and subsystem parameters; novel devices and applications; and silicon solar cells. Each of these areas includes basic research.
- The ocean thermal energy conversion program covers work in the areas of ocean thermal closed cycle power components, biofouling and corrosion, mission analysis, engineering test and evaluation, and ocean system development. This development program includes some basic research, especially in the areas of materials and heat exchangers.
- The fuels from biomass program includes research and technology development in the areas of new and improved plant species, biophotolysis, enzyme processes, the thermochemical breakdown of plant materials into synthesis gas, aquatic and terrestrial biomass production and conversion, and fermentation. Each of these areas includes basic research.
- The environmental and resource assessment program covers work in the areas of characterization of wind, environmental assessments, technology assessments, characterization of insolation, and characterization of ocean thermal gradients. The last three areas include some basic or fundamental research.
- The program concerned with solar heating and cooling of buildings includes research in the areas of surface coatings, heat transfer, thermodynamics, systems analysis, materials, optics, and mechanical design. The last four areas include basic research.

Conservation research and development (FY 1978 operating costs, $231 million). ERDA's conservation R&D efforts include programs concerning electrical energy systems, energy storage, improved conversion efficiency, industrial energy conservation, building and community systems, transportation energy conservation, and conservation outreach. Only the first two include any basic research, and the basic research represents less than 1 percent of the total conservation R&D efforts.

- The electrical energy systems program covers the areas of electric power transmission, utility applications, and systems management and structuring, with some basic research in the first of these areas.
- The energy storage program covers the areas of mechanical energy storage, superconducting magnetic energy storage, storage of energy in chemical form (e.g., as hydrogen), thermal energy storage, and applications analysis for energy storage systems. The last two include basic research.

General life sciences (FY 1978 operating costs, $23 million). This program covers topics in the life sciences selected for their importance to the bases for estimating risks to man's health and environment. The research plan for this program identifies six such topics: (1) Investigate the basic structure and functions of key organ systems for which rapid cell replacement is required for body function; (2) develop model *in vitro* cell systems that retain the normal function of cells of key or critical organs and tissues; (3) develop biochemical and cytological indicators of damage for critical organ systems; (4) conduct studies of molecular interactions, damage, and repair in cells of various animal species, including those of man, in order to generalize the types of damage and repair; (5) expand the national effort aimed at improving and perfecting the capability of extrapolating animal data to man; (6) ensure that the program supplies a continuous source of new and improved methods for rapid screening and detection of carcinogenic, mutagenic, teratogenic, and pathophysiologic damage to man. New efforts being initiated in FY 1978 on a small scale consist of exploratory biological research designed to provide a conceptual base for developing technologies for biological energy conversion and processing. The entire program is considered basic research.

Basic energy sciences (FY 1978 operating costs, $138 million). The scope of this program is broad. It extends throughout the physical sciences in areas related to energy conservation, production, conversion, and use. It serves as the central basic research arm of ERDA in the physical sciences and mathematics. It is divided into five subprograms: Materials sciences; chemical sciences; nuclear sciences; engineering, mathematics, and geosciences; and advanced energy systems.

- The materials sciences subprogram covers research in three general categories. The first, metallurgy and ceramics, includes studies in the areas of the structure of materials, mechanical properties,. physical properties, radiation effects, and engineering materials (e.g., friction and wear, corrosion and welding). The second category, solid state physics, includes studies in the areas of neutron scattering, experimental research (e.g., studies of superconductivity, of catalysts, and of surface

structure and reactivity), theoretical research, and particle-solid interactions. The final category, materials chemistry, includes work in the areas of chemical structure, engineering chemistry (e.g., electrochemical processes in batteries), and high temperature and surface chemistry.

- The chemical sciences subprogram covers research in categories called processes and techniques and fundamental interactions. The research includes studies in the areas of chemical and atomic physics, radiation sciences, combustion, thermochemistry, properties and reactions of coals, fundamentals of catalytic processes, separations, and analysis.
- The nuclear sciences subprogram covers research in the disciplines of nuclear chemistry and low energy nuclear physics (low energy in this context referring to experiments with accelerated ions at energies below the pion production threshold). The work is in the areas of charged particle research, neutron and fission research, heavy element/actinide research, and production of research materials. The last of these areas requires about 30 percent of the budget for this subprogram and involves unique facilities for both electromagnetic separation of isotopes and production of transplutonium elements in a high flux reactor.
- The engineering, mathematics, and geosciences subprogram features research in each of these quite distinct disciplines. Work in the engineering sciences is focused on topics that cut across the responsibilities of other parts of ERDA, including, for example, compilations of engineering data and systems studies of nondestructive testing. The work in mathematics would be considered almost entirely applied research within the traditions of that field. It includes studies of new concepts and methods required for the solution of mathematical models arising in the physical, engineering, and social sciences. It also includes research in the computer sciences concerning algorithms, computer architectures, programing languages, software, and computer networks. In the geosciences, the research is in the areas of geology and earth dynamics, energy resource identification and evaluation, geothermal chemistry, and solar-terrestrial-atmospheric interactions.
- The advanced energy projects subprogram is designed to nurture ideas and inventions in the tender stage shortly after their conception, as well as to carry out early development of systems without a natural home in the energy technology divisions.

The discussion in this section has been confined to ERDA programs that include research classified as basic or fundamental in the internal survey conducted in the summer of 1976. It thus excludes programs concerned with nuclear fuel cycle research and development, liquid metal fast breeder reactors, nuclear research and applications, biomedical applications, nuclear materials security and safeguards, naval reactor development, uranium enrichment, special materials production, and environmental research and development.

Another perspective on ERDA's research activities is given by examination of where the work is carried out. Among the mission agencies with major R&D programs, ERDA is unique in its heavy reliance on contractor-operated laboratories. These include nine, well-known multiprogram laboratories: Ames (Iowa) Laboratory, Argonne National Laboratory, Brookhaven National Laboratory, Lawrence Berkeley Laboratory, Lawrence Livermore Laboratory, Los Alamos Scientific Laboratory, Oak Ridge National Laboratory, Pacific Northwest Laboratories, and Sandia Laboratories. The first six are operated by universities or university consortia. The Oak Ridge and Sandia laboratories are operated by Union Carbide and Western Electric, respectively, and the Pacific Northwest Laboratories are operated by the Battelle Memorial Institute. Other contractor-operated laboratories include five more specialized physical research facilities and a dozen biomedical laboratories. Educational institutions are the contractors for each of these, and many are located on university campuses. The remaining contractor-operated facilities do not ordinarily carry out basic research; this final group includes five engineering development laboratories, nine nuclear materials production facilities, and seven weapons production and testing facilities. More than 56,000 people are employed at ERDA's government-owned, contractor-operated facilities.

ERDA also operates seven comparatively small laboratories staffed by a total of slightly more than 900 ERDA employees. This group includes the five energy research centers at Bartlesville, Grand Forks, Laramie, Morgantown, and Pittsburgh devoted primarily to fossil energy R&D; the Health and Safety Laboratory in New York City which conducts sampling and analysis of environmental materials of biological significance; and the New Brunswick Laboratory which provides support for nuclear safeguards programs. Overall, many of ERDA's programs are carried out by private contractors at their own facilities. For many demonstration projects, construction is jointly supported by ERDA and by industry.

Many of ERDA's multiprogram laboratories

operate experimental facilities used in large part by university faculty members and their students. All of ERDA's large high energy and nuclear physics facilities were built with this pattern of use in mind. Such facilities also include three of the five more specialized physical research laboratories referred to earlier—Fermi National Accelerator Laboratory, Stanford Linear Accelerator Center, and Bates Linear Accelerator Facility. The high energy and nuclear physics programs provide direct support to many of the university investigators through contracts with the individual universities, and also provide indirect support through operation of the research facilities. Taking both direct and indirect support into account, well over 50 percent of the funding for these particular programs support the research of university faculty members and their students.

Funds flow directly to universities from many other parts of ERDA. Universities play a prominent role in carrying out ERDA's research programs. The amounts budgeted in FY 1978 for support of R&D at universities by the various program management units in ERDA are as follows: $88 million from solar, geothermal and advanced energy systems (which includes the physical research and magnetic fusion energy programs); $47 million from environment and safety; $22 million from fossil energy; $5 million from national security (which includes the inertial fusion program); $4 million from conservation; and $3 million from nuclear energy. The total of $169 million excludes, of course, funds for operation of major ERDA laboratories by universities.

The diversity of ERDA's research is too great to allow simple choice of outstanding accomplishments. Many thousands of publications resulting from this research appear each year in the scientific literature. The approach chosen here will limit the discussion to two subjects. Examples will be given of recognition of research accomplishments by groups outside of ERDA, and lists will be presented of accomplishments in ERDA's separately identified programs of basic research: high energy physics, nuclear physics, basic energy sciences, and general life sciences.

The 1976 Nobel Prize for Physics was shared by Burton Richter and Samuel Ting. It recognized discovery of the psi/J particle in research supported by ERDA and carried out at the Stanford Linear Accelerator Center and at Brookhaven National Laboratory. Six other Nobel laureates remain active in ERDA programs, in particular, at Lawrence Berkeley Laboratory: Luis Alvarez, Melvin Calvin, Owen Chamberlin, Edwin McMillan, Glenn Seaborg, and Emilio Segré.

Many dozens of other major scientific awards have been made to employees at ERDA laboratories and to university scientists whose research is supported by ERDA. Recent examples include the following: the Hume Rothery Award of the Metallurgical Society of A.I.M.E. to Karl Gschneider of the Ames (Iowa) Laboratory, the Rosenhaim Medal of the British Metals Society to Gareth Thomas of Lawrence Berkeley Laboratory, the Tom W. Bonner Prize in Nuclear Physics to G. Raymond Satchler of Oak Ridge National Laboratory, the Robert A. Welch Award in Chemistry to Neil Bartlett of Lawrence Berkeley Laboratory, the John von Neumann Theory Prize to Richard Bellman of the University of Southern California, and the Davisson-Germer Award to Ugo Fano of the University of Chicago. More than 40 employees at ERDA laboratories, as well as many university investigators supported by ERDA, are members of the National Academy of Sciences or the National Academy of Engineering.

Recognition of accomplishments along somewhat different lines is provided by the IR-100 awards sponsored by the magazine, *Industrial Research.* For example, 7 of the 100 outstanding technological achievements honored in 1976 resulted from work at ERDA laboratories. These achievements concerned a new method for encapsulation of drugs, a meter for measuring tritium in liquid sodium, a new soldering process for printed circuit boards, a waste treatment system, fabrication of wire for dosimeters, a new type of composite crystal, and development of a compound parabolic converter for concentrating sunlight. The last three of these resulted directly from ERDA's basic research programs. The compound parabolic converters were originally designed to concentrate Cerenkov radiation in high energy physics experiments.

The following accomplishments were listed recently for ERDA's general life sciences program:

- Rapid microbial screening has been developed with 85 percent reliability for detection of carcinogens.
- A battery of *in vitro* and *in vivo* screening methods have been developed for mutagens.
- The role of calcium has been clarified in differentiation of heart muscle cells; this information will be important for assessing effects of chemical pollutants on, for example, the development of muscle protein.
- The structure has been determined for certain enzymes which hydrolyze proteins in living cells, and which may be related to carcinogenesis and organ damage.
- The proteins required for initiation of DNA synthesis, the most sensitive step in cell replication, are being identified.
- The detailed fine structure of important pro-

teins is being obtained in order to define their active centers.

A recent listing of achievements in ERDA's high energy physics programs leads off with the 1973 discovery of neutral currents and the discoveries in 1974 of direct lepton production and of the psi/J family, observation in 1975 and 1976 of strong spin effects in polarized proton scattering and of unusual antineutrino scattering, discovery in 1976 of pion-muon atoms, and discovery in 1976 of charmed mesons and baryons. The scientific implications of these achievements are profound. The experiments reveal a fourth "charmed" quark and a possible new lepton as among the short list of the most basic constituents of matter and energy (which earlier was limited to three quarks, four leptons, and their antiparticles). The experiments suggest that the quark binding energy in hadronic matter may exceed the GeV range and may be the manifestation of a new basic force. It appears increasingly likely that all of the basic types of forces may be unified in a single framework analogous to the equations of Maxwell (which unified electrical and magnetic forces) and Einstein (which unified mass and energy).

Recent achievements in the materials sciences part of ERDA's basic energy sciences program include the following: (1) Reduction in stress corrosion cracking of austenitic stainless steels through use of inhibitors, (2) densification of refractory mixed oxides at much lower temperatures than previously, (3) detailed analysis of the oxidation of carbon monoxide on a platinum catalyst, (4) determination of the effect of impurities on the critical transition temperature of niobium-germanium superconductor, and (5) development of a method for partitioning tritium between molten lithium and a fused salt mixture with subsequent selective electrolysis.

Achievements listed for the chemical sciences and the engineering, mathematics, and geosciences subprograms include: (1) Establishment of the scientific feasibility of three different thermochemical cycles for producing hydrogen from water, (2) determination of the temperatures and densities of major constituents of turbulent flames by Raman spectroscopy, (3) successful modeling of the cascading effect in atomic spectroscopy, (4) establishment and operation of a computer network, and (5) discovery that many ampere electric currents will be generated in the Alaska pipeline by sun-induced magnetic storms.

Achievements in the nuclear physics program and in the nuclear sciences part of the basic energy sciences program include: (1) Improved understanding of nuclear mass and electric charge distribution through high precision measurements at the Anderson Meson Physics and the Bates Linear Accelerator Facilities, (2) evaluation of the baryon resonance contributions to the properties of nuclei, (3) acceleration of the calcium isotope of mass 48 at the Lawrence Berkeley Laboratory accelerator known as Super HILAC, and (4) development of a new technique for measurement of neutron cross sections for microgram samples of actinide elements.

Current and Future Research Emphasis

The strongest growth among the basic research efforts in the physical sciences is foreseen to be in the chemical sciences and materials sciences subprograms. High percentage growth is also foreseen for work in the geosciences category, but it will start from a very small base.

Fossil fuel chemistry, combustion, and photoconversion are typical of the areas receiving increased emphasis in the chemical sciences subprogram. A variety of research projects are underway on coal, coal constituents, and catalysts, including studies of catalyst fouling and regeneration, of fossil materials characterization and conversion reactions, and of chemical and physical techniques for analysis. The fundamental combustion studies concern topics such as identification of short-lived reaction products, measurement of turbulence and reaction rates, and improvement of theories for predicting experimentally unmeasureable rates. In the area of photoconversion, expanded efforts are underway on artificial photosynthesis, photochemical generation of fuels, and photogalvanic generation of electricity.

Special emphasis in the materials sciences subprogram is being given, for example, to new studies involving electrical conduction in materials and to metals and ceramics useful for high temperature application. Specific topics include semiconductors for solar energy applications, superionic materials for batteries, electrical conduction in ceramics for magnetohydrodynamic and fusion energy applications, superconductors for electrical storage and transmission, ceramics for turbine applications, high temperature coatings, refractory alloys for high temperature batteries, corrosion at high temperatures, and high temperature composite materials.

Two construction projects are just getting underway for major facilities serving the chemical sciences and materials sciences subprograms. A combustion research facility will be built adjacent to the Sandia Laboratories site at Livermore, Calif. A synchrotron radiation facility will be built at Brookhaven National Laboratory. Both have been designed as user facilities so that a major share of

the experiments can be carried out readily by scientists from universities, from other Federal laboratories, and, in some instances, from industrial laboratories. The combustion research facility will feature a variety of laser and other systems for diagnosing fossil fuel flames and explosions. The synchrotron radiation facility will provide a remarkably useful source of electromagnetic radiation for pioneering research in the materials, molecular, and life sciences.

These facilities reflect a trend underway in many parts of science. More research in more fields is becoming centered around major regional or national experimental facilities. Their importance to basic energy research is almost sure to increase.

Use of centralized facilities will continue to be a way of life for most high energy and nuclear physicists. Several of the construction projects now underway for these fields were mentioned earlier. The colliding beam facility known as ISABELLE is expected to be the next step in implementing the long range facility plans for high energy physics. For heavy ion physics, the next major step in this country is likely to be an additional stage of acceleration for the Holifield Heavy Ion Facility.

In the general life sciences program, the research plan includes six major topics, a number of which were described earlier in the discussion of types of relevance. The subjects emphasized in the research plan in brief summary are: (1) Organ systems with rapid cell replacement, (2) model *in vitro* cell systems, (3) damage indicators, (4) types of damage and repair, (5) relating animal data to man, and (6) bases for new screening and damage detection methods.

No attempt has or will be made here to present a comprehensive picture of areas of future emphasis. As this is written, the primary Federal responsibility for energy R&D is being brought into the new Department of Energy. The views of the future are unusually clouded at this time. Still, some features of the landscape can be discerned. They form the general context in which the basic research will be carried out. Continued urgent attention will be required on each means holding promise for meeting near term energy needs or for minimizing the growth of these needs. The necessity for proceeding rapidly toward expanding our base of energy resources for the longer term will demand marshalling of an even greater fraction of our national scientific and engineering talent than is now devoted to this purpose. Difficult and, at times, distressing choices will also be demanded. The place of basic research in this enterprise has yet to be spelled out. Experience calls for a substantial role for programs of sustaining research, for incorporation of technology-focused basic research within the framework of the longer term development efforts, and for the welcoming of special basic research missions.

Organization and Management of Research Activities

It is already clear as this is written that scientific activities within the Department of Energy will be organized rather differently from the way they were within ERDA. A brief historical sketch seems in order. This section will highlight some features of ERDA's approach and will avoid forecasts concerning the Department of Energy.

The Energy Reorganization Act establishing ERDA fixed the central features of the program management structure. The act called for six program assistant administrators, one for research, development, and demonstration concerning each of the following areas: Fossil energy; conservation; environment and safety; nuclear energy; national security; and solar, geothermal, and advanced energy systems. A number of program divisions report to each assistant administrator. The work of the divisions is clearly described by the name of the area except in perhaps three instances. The national security area includes the inertial fusion program. The advanced energy systems area includes the magnetic fusion energy program, as well as the physical research programs—high energy and nuclear physics and basic energy sciences. The Assistant Administrator for Environment and Safety has been assigned broad responsibilities for assuring the adequacy of environmental R&D throughout the agency. A post of Deputy Assistant Administrator for Physical Research was also established by ERDA in the Office of the Assistant Administrator for Solar, Geothermal and Advanced Energy Systems with line responsibility for the high energy and nuclear physics and the basic energy sciences programs, and, in addition, with overview responsibilities for physical research activities in other parts of the agency.

More than 99 percent of ERDA's RD&D is carried out under a variety of contracts. The staffs of the ERDA program divisions are responsible for program formulation, allocation of funds, and program review. A major part of the responsibilities for negotiating and administering contracts and overseeing contractor performance is carried out by ERDA field offices. The basic research funded by ERDA is carried out primarily at universities and at government-owned, contractor-operated laboratories. For funding basic research by individual investigators at universities, the mechanics of the process used by ERDA has ordinarily been similar to the one used by NSF—with unsolicited

proposals, written peer reviews, and funding decisions and on-site reviews by headquarters staff.

The gross outlines sketched here fail to touch the sources of the flavor and vitality of ERDA's basic research. It has been stretched, refitted, and remolded during the hectic 30 plus months of ERDA's existence. It survived, certainly larger and more diverse, and probably stronger than when ERDA began. The biggest pieces saw ERDA come and prepare to go, with the magnificent accelerators still probing the innermost secrets of physics. The scientists, many there from the first and many who were added, have done outstanding work. The ERDA laboratories, each with its institutional pride, struggled to change and earn new and broader roles and still to keep their basic research creative and fruitful and among the best in the world. It is too soon to be sure how well they succeeded. The signs are hopeful. They augur success in a new setting.

ENVIRONMENTAL PROTECTION AGENCY

Submitted by Stephen J. Gage, Acting Assistant Administrator for Research and Development

EPA's Mission

The aim of the U.S. Environmental Protection Agency (EPA) is to protect the health and welfare of the American people by controlling environmental pollution hazards. The Agency sets and maintains air and water pollution standards, establishes drinking water standards, regulates the sale and use of pesticides, sets standards for noise and ambient radiation, develops techniques and procedures for solid waste management, studies toxic substances, conducts research, and demonstrates new pollution control methods and technology.

EPA is an independent regulatory agency formed under a reorganization plan on December 2, 1970, from components of several Federal departments and agencies. Major Federal laws administered by the Agency are shown in Table 1.

Table 1. Summary of legislative authorities.

Public Law No.	*Title*	*Year Passed*
78-410	Public Health Service Act	1944
89-272	Solid Waste Disposal Act	1965
91-190	National Environmental Policy Act	1969
91-604	Clean Air Act Amendments	1970
92-500	Federal Water Pollution Control Act Amendments	1972
92-532	Marine Protection, Research and Sanctuaries Act	1972
92-574	Noise Control Act	1972
92-583	Federal Insecticide, Fungicide Rodenticide Act Amendments	1972
93-523	Safe Drinking Water Act	1974
94-469	Toxic Substances Control Act	1976
94-580	Resource Conservation and Recovery Act	1976
94-475	Environmental R&D, and Demonstration Act	1976

Source: EPA

The Agency has about 9,800 employees and an annual operating budget of about $845 million.

EPA also administers grants to the States for construction of municipal sewage treatment facilities. For fiscal years 1973 through 1976, Congress authorized $18 billion for this program. In 1977, EPA will spend $5.6 billion.

The Administrator of EPA is assisted by a Deputy and by six Assistant Administrators responsible for planning and management, enforcement, water and hazardous materials, air and waste management, toxic substances, and research and development. Offices that provide support services include: International Activities, Legislation, Federal Activities, Public Affairs, Civil Rights, and General Counsel. To ensure that the agency is responsible to the needs of people, it has developed a network of 10 regional offices.

Role of Research

The Office of Research and Development (ORD), under the direction of an Assistant Administrator, functions as the principal scientific component of EPA. Its fundamental role is to produce scientific data and technical tools on which to base sound national policy in the development of effective pollution control strategies and the promulgation of adequate and viable environmental standards. It is the responsibility of ORD to establish programs that will provide answers to a myriad of complex environmental questions, including:

- How can we detect, identify, measure, and monitor pollutants?
- Where do pollutants come from, how do they get there, and what happens on the way?
- What levels of pollutant discharge from specific sources can be permitted while still attaining defined ambient quality standards?
- What are the health and ecological effects of pollutants on man, other life forms, and the inanimate environment?

Table 2. Historical trend of ORD resources.

	FY 1971	FY 1972	FY 1973	FY 1974	FY 1975	FY 1976	FY 1977	FY 1978[1]
Total new obligational authority (in thousands of dollars)	$101,764.0	$123,437.3	$129,807.1	$144,320.9	$282,444.2[2]	$252,423.6	$241,949.4	$245,666.1
Authorized personnel	1,379	1,705	1,914	1,814	1,750	1,750	1,727	1,729

[1] FY 1978 Carter budget.
[2] $134 million energy/environment program added.

Source: EPA

- What technologies are available for controlling pollution; what are their design and operational requirements, efficiencies, reliabilities, and cost; and how can they best be transferred into actual practice on a national scale?

ORD has about 1,875 people representing more than 60 different disciplines and specialties. ORD is organized with 4 major operating offices and 19 supporting laboratories. About 220 ORD people are located in Washington, D.C., and more than 1,600 are in the laboratories and field sites. The total research budget is more than $245 million, 75 percent of which is spent on grants and contracts and on interagency agreements; the remaining 25 percent is spent on in-house studies. (See Table 2 for trends in ORD resources.)

Although ORD is organized into four offices, its activities must be viewed as an interrelated set. In addition to close coordination within ORD's offices, ORD's activities must be coordinated with other Federal environmental research activities and with other parts of EPA. It is estimated that approximately $185 million is spent by EPA on outside R&D for various technical surveys and studies that have research value. ORD's mission-oriented or problem-oriented approach to specific problems often requires coordination of ORD offices.

The major R&D activities most closely related to the EPA mission and to the advancement of the scientific state of the art are:

1. Acquisition and evaluation of information
2. Cost of benefit determination (social and economic)
3. Standardization of sample taking, analysis, monitoring, and reporting techniques
4. Development of abatement and control processes technology
5. Determination of the fates and effects of pollutants
6. Investigation of fundamental physical, chemical, and biological characteristics and processes
7. Investigation of alternative economic, social, legal, and technical strategies for an improved environment.

Table 3 provides a summary of the resources budgeted by program area during the four most recent fiscal years. Table 4 illustrates the formal budget breakdown categorized by specific media for legislative purposes.

The specific media relate to natural and manmade "sources." These latter sources can be characterized as stationary or mobile, point (i.e.,

Table 3. Office of Research and Development comparison of planned resource levels in fiscal years 1975, 1976, 1977, and 1978 by major program area.

Program Area	FY 1975	FY 1976	FY 1977	FY 1978[1]
	(millions of dollars)			
Health and ecological effects	$ 62	$ 71	$ 64	$ 63
Industrial processes	27	21	19	18
Public sector activities	28	30	30	36
Monitoring and technical support	19	27	26	25
Energy/environment	133	100	96	96
Other (ORD program support and management, ADP, etc.)	9	5	7	7
Total ORD program	$278	$254	$242	$245

[1] FY 1978 Carter budget.

Source: EPA

Table 4. Office of Research and Development comparison of planned resource levels in fiscal years 1975, 1976, 1977, and 1978 by media.

Media	FY 1975		FY 1976		FY 1977		FY 1978[1]	
	$(M)	Positions	$(M)	Positions	$(M)	Positions	$(M)	Positions
Air	53.6	423	48.5	395	43.0	460	40.2	465
Water quality	41.6	555	44.0	556	41.3	546	42.1	526
Water supply	5.9	91	12.7	103	13.6	104	15.6	109
Solid wastes	5.7	23	4.1	22	4.1	22	7.7	22
Pesticides	7.1	115	8.4	122	8.3	121	8.3	121
Radiation	2.6	72	1.7	50	0.8	30	0.8	30
Noise	–	–	–	–	–	–	–	–
Interdisciplinary	18.1	261	28.0	275	25.9	214	25.4	187
Toxic substances	1.2	11	1.3	7	1.4	6	1.9	45
Energy	133.1	–	100.0	123	96.4	123	96.4	123
Program management and support	9.2	199	5.0	99	7.2	101	7.2	101
ORD program total	278.1	1,750	253.7	1,752	242.0	1,727	245.6	1,729

[1] FY 1978 Carter budget.

Source: EPA

industrial), or nonpoint (i.e., agricultural) and other kinds of human—or more specifically, municipal—activities. Emissions and wastes from each source must be characterized by physical and chemical properties in the process stream and at the source output.

Capabilities to characterize environmental contaminants (i.e., determine their chemical composition) and measure ambient concentrations must be developed. Effects research depends critically on the availability of effective characterization and monitoring techniques for all forms of wastes, including gases, liquids, solids, and energy.

Overall assessment of health, ecological, and other welfare effects must be figured on concentrations, as well as physical properties and chemical composition, of the environmental pollutant observed. The element of environmental loading must provide the necessary quantitative and qualitative input in the proper format to assess exposure of all receptors including humans, animals, plants, materials, etc. The effects element is concerned with acute, subacute, and chronic effects and with effects characterized as reversible and irreversible. Since establishment of environmental standards and regulations are reasons for much of this research, close coordination and feedback of effects research and abatement methods R&D are essential.

The last element concerns itself with identification and development of cost-effective approaches to pollution control. Obviously, relevant costs, risks, and benefits of feasible control options must be evaluated. Such control measures can range from "hard" technology modifications (e.g., add-on devices, process change, resource recovery, etc.) to socioeconomic implementation instruments (i.e., incentives, land use regulations, etc.). Finally, a quality assurance effort of monitoring methods is required for implementation and effective enforcement of any standard or regulation.

Examples of Research

ORD's 14 research subprograms are integrated into this kind of framework. No one R&D effort can stand alone; i.e., most of ORD's outputs contain interrelated inputs of more than one subprogram. The mission of EPA requires this, and the nature of solutions to environmental problems demands no less.

Health Effects, Air Exposure

FY 1977 plan. This plan calls for research to:

- Refine estimates to health effects related to short-term nitrogen oxides exposure around point sources.
- Refine the acid sulfate aerosol health impact and impact of trace metals in primary smelter communities.

- Delineate chemical composition and particle size and conduct toxicity screening for selected pollutants.
- Characterize sulfur oxide and oxidant interaction in the Southern California area.
- Evaluate health consequences of conversion from fuel oil to coal in selected electric power generating plants.
- Develop short-term exposure data for sulfur oxides, nitrogen oxides, oxidants, and selected particulates.

Five-year plan. The five-year plan research effort is slated to:

- Reassess exposure-response data for criteria and other pollutants collected from the community health environmental survey system (CHESS).
- Develop better exposure-response functions for estimating health risks of criteria pollutants, sulfate, and nitrate aerosols.
- Determine the significance of potentially dangerous trace substances, hazardous materials, and unsuspected toxic substances to man.
- Identify the interactions in health effects of criteria and noncriteria pollutants.
- Describe interactive effects of multiple environment stress factors.
- Evaluate adverse health risks associated with indoor pollutants.

Toxic Substances

The purpose of the toxic substances work is to assess toxicity of inorganic and organic contaminants that reach people in a number of ways. The current research evaluated—through use of animal testing—health effects of fibrous amphiboles, lead and the pesticide baygon, cadmium, organic pollutants as influenced by trace metals, and dioxin and dibenzofuran. This work supports the air and water health effects research as well and anticipates legislation on toxic substances control.

FY 1977 plan. Under the FY 1977 plan, there will be reports on:

- Toxicity of fibrous amphiboles considered as carcinogens and cofactors.
- The combined effects of certain trace metals and certain pesticides on the rate of metabolism of aminopyrene and antipyrene in rats.

Five-year plan. This plan calls for:

- A report on carcinogenicity and toxicity of fibrous amphiboles.
- Development of biochemical methods to screen organic and inorganic pollutants for specific biological activity potentially hazardous to human health.

Correlating health effects with total human exposure to harmful substances. Long-term integrated exposure assessment and retrospective epidemiological research to evaluate associations between the occurrence of cancer and other chronic diseases and environmental pollution, including development of capability for exposure assessment concepts, is an ongoing research program concerning toxic substances.

Biological monitoring and tissue archiving to establish baseline levels. The cooperative program with the National Bureau of Standards on a design and feasibility study of a tissue bank has been extended into a pilot National Tissue Bank for long-term archiving of human tissue.

Response of ecosystems to multiple environmental stresses. To meet Agency long-term requirements for ecosystems research and assessment of the environmental impact of pollutants in aquatic systems, research is ongoing and will be supplemented to: (1) Develop methods to improve measurement of organism and ecosystem level effect of pollution stress, and develop and improve methods to determine ecosystem response parameters; and (2) determine the ecosystem response and develop predictive capability to describe the impact of single and complex stresses including nutrients, pesticides, disinfectants, complex industrial wastes, and hydrocarbons from single spill events, point source long-term discharges, and nonpoint source drainage basin inputs. New initiatives in the development of complex effluent effects will include development and testing of microcosms at discharge sites.

Identification and characterization of environmental processes and systems and resulting exposure analysis. Research to identify, characterize, and quantify significant environmental transport and fate processes is both anticipatory and long-range. It provides scientific bases for the development of predictive exposure assessment methodologies for existing organic and inorganic chemicals and nutrients and for new chemicals prior to their mass production and release into the environment.

Water Quality Models

Comprehensive basin water quality models with point and nonpoint source inputs, socioeconomic implications, and energy conservation inputs will be provided in research applications reports, scientific papers, and problems reports, including model user manuals and card decks as well as hands-on demonstration, technical assistance, and feedback. Research application and problem-oriented reports include an analysis of the environmental applicability and limitation of available information.

FY 1977 plan. This plan calls for:

- Development of an evaluative model for predicting the distribution and half-life of mercury among the various substrates of fresh surface water ecosystems and calibrating it for malathion.
- Development of procedures for estimating water quality (relative to sediment and nutrients) that would exist in a given watershed under various hypothetical land use practices (including return to a "natural" state).
- Development of additional source-loading functions to predict pollutant loads to streams from nonpoint sources.
- Coupling nonpoint source-loading models to basin water quality models for use in assessing water quality impacts (relative to biological oxygen demand, sediment, and nutrients tests) of both nonpoint and point sources.

Five-year plan. The five-year plan will:

- Provide EPA's Office of Toxic Substances (OTS) and ORD/Office of Health Ecological Effects (OHEF) with suitable multimedia microcosm techniques (and user instructions) for use as tools in predicting environmental distribution of various classes of pollutants that would result if released into the environment.
- Complete laboratory evaluation of heavy metals (in water) submodel, verify (in laboratory and experimental field systems), and calibrate for mercury, and provide user manuals to OTS and to EPA's Office of Pesticide Programs (OPP) and Office of Water Planning and Standards (OWPS).
- Expand the pesticide (in water) submodel to handle persistent pesticides and highly volatile pesticides; verify (in laboratory and experimental field systems), and calibrate.
- Provide improved or additional nonpoint source loading models coupled to basin water quality models.

Industrial Processes Program

This program includes two research subprograms: The minerals, processing, and manufacturing industries, and the renewable resources industry. The split is made on the character of sources being investigated—point and nonpoint sources, respectively.

The minerals, processing, and manufacturing industries subprogram considers point sources in water, air, and residue pollution produced by industry. Research, development, and demonstration (RD&D) in this subprogram focuses on mining, manufacturing, service, and trade industries with activities that range in scope from extraction to production of raw materials and processing of materials into intermediate and consumer products.

Research on water industrial processes supports the "best available technology" (BAT) requirements of the Federal Water Pollution Control Act (FWPCA) through development and demonstration of new or improved cost-effective technology with industrywide applicability, short-term achievability, and long-term viability. This research provides primary data for establishing economically and technically feasible effluent guidelines and treatment parameters for industrial liquid-waste discharge permits. The research also considers technology for preventing and controlling accidental spills of hazardous materials.

Industrial processes water research will focus on development and demonstration of technologies for closed-cycle systems except when open-cycle technology research is required for standards verification or closed-cycle is not feasible. Roughly 32 of the total 593 regulatory categories will be affected by the more viable technologies demonstrated.

Hazardous incident research will continue on control and minimization of spill damage and will provide data for the new EPA spill regulations for hazardous materials.

Over the longer term, industrial processes water research will continue to respond to technology requirements of the FWPCA. Increased attention will be directed to hazardous waste disposal and demonstration of technology for specific critical industrial sources.

Research on air industrial processes supports the technology requirements of the Clean Air Act (CAA) through development and demonstration of new or improved cost-effective technology with industry-wide applicability, short-term achievability, and long-term viability. These requirements support implementation of ambient air quality standards and the development of new source performance standards (NSPS).

Near-term air pollution control technology research focuses on assessing the magnitude of problems and the state of the art for control of noncriteria and hazardous pollutants. Work has begun on transferring technology for particulate control to industry. The results of the assessment studies will provide identification, characterization, and prioritization of industrial sources of hazardous pollutants. This information will permit development of national strategies to control industrial air pollution.

Over the longer term, activities will continue to characterize and assess air pollution problems from industrial sources and identify available technology for pollution control and its economic implication. This information will continue to be used

to formulate specific technology requirements and strategies to control air pollution from industrial sources. Demonstrations of control technology for high priority sources will also continue.

Finally, the FWPCA requires that a list of hazardous materials be issued and that the list serve as a basis for recovery for damages resulting from spill of such materials. The expectation is that more than 500 primarily industrial materials will be identified.

EPA must therefore rely on a technology-based standard to ensure that exposures do not present substantial risks to people. Anticipatory RD&D on control of emissions of potentially hazardous materials can serve the Nation well by providing assessments for the feasibility of control of such materials.

Status of technology. To date, this technology RD&D has provided the technical basis for an estimated 100 industrial categories at the "best practical technology" (1977) and "best available treatment" (1983) levels of control. Additional technology gaps and associated RD&D needs, if any, for specified best practical technology levels may be identified in legal tests of regulations.

The data base on which decisions can be made for industrial air pollution control is generally weak. Consequently, a large assessment program has been initiated to determine what sources may require control technology RD&D in the future.

Five-year plan. To significantly enhance protection of the environment from industrial pollution sources by the mid 1980's, the minerals, processing, and manufacturing subprogram is recognized as a high priority RD&D area. Because of the time restraints in the FWPCA to achieve the stringent control levels established and anticipated timing of additional new source performance and hazardous material standards and new toxic substance standards, research and development must be accelerated in fiscal years 1978, 1979, and 1980.

Monitoring and Technical Support Program

The monitoring and technical support program includes RD&D activities and direct assistance and support to all of EPA. The components of this program include:

- Measurement techniques and equipment development
- Quality assurance
- Technical support.

Techniques and equipment development involves development, evaluation, and demonstration of field and laboratory measurement and monitoring methods and instrumentation. Efforts are directed toward achieving capability to identify and measure all pollutants of concern in the most cost-effective manner.

Techniques and equipment development over the long term will continue to address methods and techniques for air, water, and multimedia monitoring systems including advanced remote environmental monitoring systems.

Quality assurance serves all environmental monitoring activities of EPA. This activity focuses on standardizing measurement methods, providing standard reference materials and samples, developing quality control guidelines and manuals, onsite evaluation of analytical laboratories, interlaboratory performance tests, monthly cross-check samples studies, studies on methods for laboratory accreditation, studies on automation of laboratory instruments and data handling, and participation in regional quality control activities.

Technical support is the scientific and technical assistance the research program gives to other components of EPA by using the expertise of ORD personnel and available ORD facilities. This subprogram includes responsibility to deliver results of ORD's efforts.

Five-year plan. The monitoring R&D is characterized as level-of-effort. Accordingly, much of the program looks the same for individual years in the five-year plan. Correcting deficiencies in candidate and reference monitoring methods and developing new methods as needs arise will continue to get attention with focus always on current high-priority pollutants.

However, there are some relatively long-range projects and additional level-of-effort activities planned for implementation in FY 1977 or beyond. Further, certain existing programs will get more emphasis in FY 1977 and beyond. Some examples of these areas are described below:

- Water monitoring methods equivalency program: Present regulations allow only discharges to apply for approval of alternate methods for measuring pollutants in industrial and municipal effluents. Manufacturers of monitoring instruments have no direct recourse for demonstrating the equivalency of their products to the promulgated test procedures. The most reasonable solution to this problem is to set up a program similar to the ambient air equivalency program. This requires promulgation of new regulations or amendments to existing ones.
- Agencywide laboratory automation system: Laboratory automation consists of applying small computers (mini-computers) to sophisticated laboratory instruments to control their operation, process their data, and generate reports for laboratory scientists. With this technology, it is possible to increase the quality and quantity of laboratory data and provide substantially increased capabilities with no

increase in personnel. This advanced technology is of particular importance to monitoring laboratories that must accurately analyze large numbers of samples to support enforcement actions.

ORD plans to continue to capitalize on monitoring capabilities developed by other organizations. The transfer into and application by EPA of advanced technology developed outside the Agency has been accomplished by pilot projects on real problems. The regions and other EPA Offices continue to need total monitoring systems because these systems often represent a way of completing pressing tasks in a faster, more cost-effective manner.

Environmental R&D in other Federal agencies. The EPA is but one of many agencies with environmental R&D that concerns itself with some aspect of environmental pollution. This could include emission, transport processes, and fate impacts or effects, and control technologies and management methods for pollutants. Such research covers air and water pollution, pesticides, solid waste, water supply, noise, radiation, and toxic and hazardous substances.

The National Environmental Policy Act (NEPA) required Federal agencies to consider environmental consequences of their actions. Such a demand led to an increase in environmental R&D in many areas. While EPA is clearly mandated to be the lead agency in environmental R&D, it must be recognized that the resources available to ORD represent about 20 percent of the total Federal commitment to environmentally related R&D. The mission of other Federal agencies necessitates environmental R&D. Therefore, EPA has the responsibility to ensure that environmental R&D capabilities in other agencies are not unnecessarily duplicated but are recognized and utilized as efficiently as possible.

Technology transfer program. The object of the technology transfer program is to have an effective impact on the construction, installation, and operation of pollution control and abatement facilities; to ensure that the latest viable technologies are transferred to potential users; and to eliminate the possibly large investment in obsolete facilities.

The program's primary function is to bridge the gap between research and full-scale use by evaluation and transfer of newly developed successful technologies to consulting engineering firms; municipal, industrial, and State design engineers; city managers; directors of public works; industrial managers; conservation groups; and others exerting influence over the design and construction of all pollution control and abatement facilities.

A further goal is to establish the newly emerging technologies as practical and feasible alternatives on a national basis, to be routinely considered and evaluated in the planning of these facilities.

A continuing series of publications is being prepared and disseminated by the technology transfer program for use by the various categories of potential users.

Summary

Basic research has several important roles in EPA's overall research effort. It is essential to have a fundamental scientific base on which to build applied research and development. Within EPA, basic research on ecosystem modeling and the fate and transport of pollutants aids in determining the effects of pollution of an ecosystem as a whole. Basic research jointly sponsored by EPA and the Food and Drug Administration (FDA) at the National Center for Toxicological Research aids health effects researchers by illuminating underlying mechanisms and relationships of observed toxicities. Increased knowledge in this area may make it easier to predict the toxicity of an untested chemical or indicated treatment or prevention of a chemical's toxic effects.

Interest in problems of growth and concentration of population seems to be increasing. While the research arm of EPA does not formally state 10-year goals, it is likely that the population aspects of the environment will be a major new area of research.

The EPA derives its regulatory goals and objectives from legislative mandates and Executive initiatives. The ORD serves to support the rest of the Agency in carrying out its program and achieving its goals. Therefore, throughout the planning and implementation of the research program, ORD must continually seek guidance from the various Agency components to determine, and to be responsive to, their research requirements and priority needs. At the beginning of each planning cycle, the Assistant Administrator for Research and Development requests research guidance from the Administrator, the Deputy Administrator, the other Assistant Administrators, and the Regional Administrators. This guidance is forwarded to the appropriate ORD office. Each year, ORD prepares a program plan for the following fiscal year. This is based on input from ORD's major headquarters components, semiannual program reviews, the Agency's budget year planning guidance, and the Agency's current year program adjustments. It indicates the degree of emphasis on various pro-

grams for that fiscal year. Laboratory directors may also make specific research proposals. The syntheses of all of the previously described guidance is the "Agency research statement," a sort of "master" research plan. Specific requirements of the agency research statement are described in objective statements. The laboratory directors are responsible for translating these documents into plans for accomplishing the objectives. Unsolicited research proposals from outside parties may be accepted if they are consistent with the Agency's overall objectives. The supportive nature of EPA's research segment is part of the reason that its research is largely applied. While basic research is ultimately essential to continued support, it is likely to be deferred in favor of more immediate needs.

Whether the research necessary to accomplish the Agency's goals is undertaken in-house or extramurally is dependent on the availability of the scientific expertise, facilities, and manpower in the Agency laboratories. If the research is undertaken outside the Agency, it is normally through competitive grants and contracts. Proposals are reviewed in-house as well as by outside experts for feasibility, cost and scientific capability of the researchers.

There is not official differentiation between basic and applied research in EPA. In fact, which research falls into which category is open to debate. Procedures for initiation, review, and termination of R&D projects are the same for all research. One proposed solution to EPA's problem of insufficient basic research is to separate basic research from applied research in the early planning stages so that it may be better protected.

The Agency has increased its basic research since its inception in 1970. The need for basic research in EPA is certainly more generally recognized. Perhaps it is simply a question of time.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Submitted by A.M. Lovelace, Deputy Administrator

NASA Mission

The National Aeronautics and Space Administration (NASA) is the civilian agency of the United States Government charged, in Section 203 of the Space Act,[1] with the responsibility to:

(1) Plan, direct, and conduct aeronautical and space activities;
(2) Arrange for participation by the scientific community in planning scientific measurements and observations to be made through use of aeronautical and space vehicles, and conduct or arrange for the conduct of such measurements and observations; and
(3) Provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof.

These activities are defined in Section 103 of the act as:

> . . .(A) research into, and the solution of, problems of flight within and outside the earth's atmosphere, (B) the development, construction, testing, and operation for research purposes of aeronautical and space vehicles, and (C) such other activities as may be required for the exploration of space; . . . .

Section 102 of the act defines the objectives to which these activities should contribute as:

(1) The expansion of human knowledge of phenomena in the atmosphere and space;
(2) The improvement of the usefulness, performance, speed, safety, and efficiency of aeronautical and space vehicles;
(3) The development and operation of vehicles capable of carrying instruments, equipment, supplies, and living organisms through space;
(4) The establishment of long-range studies of the potential benefits to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes;
(5) The preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere;
(6) The making available to agencies directly concerned with national defense of discoveries that have military value or significance, and the furnishing by such agencies, to the civilian agency established to direct and control nonmilitary aeronautical and space activities, of information as to discoveries which have value or significance to that agency;
(7) Cooperation by the United States with other nations and groups of nations in work done pursuant to this Act and in the peaceful application of the results thereof; and
(8) The most effective utilization of the scientific and engineering resources of the United States; with close cooperation among all interested agencies of the United States in order to avoid unnecessary duplication of effort, facilities, and equipment.

The mission of the NASA thus is to conduct a program of research and development aimed at contributing to the Nation's broad objectives in aeronautics and space as defined in the quoted excerpts from the Space Act. NASA has developed a set of functional goals, one for each of its program areas, to serve as ends toward which its programs and projects should strive. These functional goals, with the program areas in italics, are:

- To observe the physical and chemical processes occurring in the universe, in order to determine the origin and the evolutionary processes of the universe as a whole, the solar system, and of the earth, as well as the origin and distribution of life in the universe,

[1] National Aeronautics and Space Act of 1958. 72 Stat. 426 Amended (42 U.S.C. 2452).

through maintaining a strong program in *space science and exploration.*

- To bring the benefits of space and space technology to bear for the direct and immediate benefit of man through the monitoring of the earth's resources from space, the monitoring and predicting of the earth's environment, the strengthening and maintenance of U.S. leadership in world space communication, the demonstration of the potential of space techniques to manufacture unique and economically viable new products, the undertaking of other R&D efforts in *applications-oriented* activities, and to facilitate the transfer and *utilization* of NASA technology in cooperation with the wide range of users and nonspace mission-oriented agencies.
- To generate advances in aeronautics that provide feasible, more economical, efficient, and environmentally acceptable air transportation systems responsive to current and projected needs; to maintain the position of the United States in the international aviation market; and to provide support in maintaining the superiority of the Nation's military aircraft through an *aeronautics research and technology program.*
- To provide expanded *space research and technology* options as a national resource which can serve to evolve and provide technology readiness to support new initiatives in space exploration, applications, and transportation.
- To make space more accessible to both domestic and foreign users through development and operation of economical *space transportation* and the operation of an efficient *tracking and data acquisition* system.
- To provide a supporting research and technology base in terrestrial energy and ground propulsion and provide for the practical application of aerospace technology to the development of terrestrial energy conversion systems and ground propulsion, including establishing the practicability of "satellite power system" concepts through a cooperative *energy applications* R&D program with the Energy Research and Development Administration (ERDA) and other agencies.

Definition of Basic Research

NASA defines basic research as work directed toward an increase in fundamental knowledge, both general and specific, of physical and life science properties and processes relevant to aeronautical and space activities. By way of contrast, applied research is defined as the application of the knowledge gained through basic research to specific problems associated with the conduct of aeronautical and space activities.

NASA does not use the categories of basic research and applied research in structuring and managing its research programs, but does analyze its research and development (R&D) programs to determine relative funding proportions in basic and applied research. Those data are provided annually to the Office of Management and Budget (OMB) and the National Science Foundation (NSF). In that report, all of NASA's aeronautics programs are classified as basic or applied research. In the space programs, however, NASA excludes from research the funds associated with development of the spacecraft and launch vehicles, and development and operation of tracking and data acquisition systems, which make certain of the research possible. Included in the research category are:

- Theoretical and experimental laboratory research
- Other ground-based research (including analysis of samples returned from space flight missions)
- Analysis of data (including data returned by space flight missions)
- Studies of future scientific mission objectives
- Development of scientific instruments and payloads
- Development and launch of small satellites and sounding rockets (when carried out for research purposes).

In addition, when they are readily identifiable, the basic (or applied) research portions of major space flight projects, such as development of scientific instruments and payloads, are included as basic (or applied) research.

The principal disciplines in which NASA's basic research is conducted are:

- Physical sciences, e.g., astronomy, astrophysics, cosmology, solar physics, physics of the interplanetary medium.
- Environmental sciences, e.g., earth and planetary atmospheres, geology and planetology, seismology, oceanology.
- Life sciences, e.g., exobiology, space medicine, environmental biology.
- Engineering sciences, e.g., fluid mechanics, aerodynamics, electronics, materials, structural mechanics, power, propulsion.

Included in the preceding list are both disciplines that are directly associated with aeronautics and space and others that, though not directly associated, have elements that can best be investigated using aeronautical or space systems. Some

basic research is also conducted in the fields of science of psychology, mathematics and computer sciences, and social sciences.

Role of Basic Research

It is evident from the Space Act that one of NASA's principal missions is the conduct of basic research itself—provided that it is relevant to aeronautical or space activities. As noted in the preceding section, basic research is conducted for the purpose of increasing knowledge in many branches of science relevant to aeronautics and space. Chief among these are the physical, environmental, life, and engineering sciences. In addition, however, this basic research contributes to NASA's accomplishing its other aeronautics and space missions as well. Specifically, NASA's basic research:

- Provides, through the engineering sciences, the fundamental knowledge to make possible advances in aeronautical and space technologies which are themselves a NASA objective, and which contribute to the development of aeronautical and space vehicles of improved capability, performance, and economy. Improved aeronautical vehicles are the responsibility of others, e.g., the Department of Defense (DOD) or the private sector. Improved space vehicles are within the purview of NASA and make possible further space research and exploration.
- Provides, through the environmental sciences, the fundamental knowledge to aid in identification and realization of the benefits that can accrue from applications of aerospace technology to observing and predicting weather, climate, and ocean conditions, locating and describing natural resources, and surveying the physical environment.
- Provides, through the life sciences, the fundamental knowledge of man and his ability to survive and perform in space that contributes importantly to the achievement of manned space flight.
- Maintains a highly skilled and motivated scientific team, both within and without the Federal establishment, and the institutions to support them in carrying out the NASA mission.

Examples of Basic Research

Numerous examples exist of NASA's support of basic research in aeronautics and space sciences. In space science, they are, in many cases, associated with successful space flight projects, and the research conducted is a direct out-growth of data and observations from instruments carried by the spacecraft. In aeronautics, they result from theoretical and laboratory work and from flights of experimental or testbed aircraft. Both in-house and out-of-house investigators are usually involved in these research activities, and no distinction is herein drawn between them. Some of the more significant examples are:

- Investigation of the structure, composition, and properties of the terrestrial planets (Mars, Venus, Mercury) and their atmospheres. Flight projects included Mariners 4, 6, 7, and 9 (Mars), Mariner 5 (Venus), Mariner/Venus/Mercury, and Vikings 1 and 2 (Mars).
- Investigation of the structure, composition, and properties of the moon, using data acquired in the Ranger, Surveyor, and Lunar Orbiter programs, and data and samples returned from the Apollo lunar exploration program.
- Investigations of the outer planets (Jupiter, by Pioneers 10 and 11).
- Investigations of the structure, composition, radiative properties, and dynamics of the sun. Many space flight projects contributed, including Orbiting Solar Observatories (OSO) and the Apollo Telescope Mount carried on the manned Skylab spacecraft.
- Investigations in ultraviolet and high energy astronomy. Flight projects included Orbiting Astronomical Observatories II and III, the Uhuru satellite, and the Small Astronomy Satellites.
- Research on the origin of life and the search for extraterrestrial life.
- Research on the composition and structure of the earth's atmosphere, using sounding rockets, balloons, and satellite infrared and microwave measurements.
- Research in microgravity materials processes, through experiments carried on board rocket and satellite systems containing various classes of experiments involving the physics and chemistry of materials.
- Research in computational fluid dynamics, utilizing the powerful computer systems that have become available in recent years. These computers have made possible basic research of fluid flow involving complex configurations and the difficult-to-handle transonic flow regime.
- Research in supercritical airfoil aerodynamics, providing new concepts in airfoil design that are leading toward applications that in-

crease efficiency of transport aircraft, general-aviation airplanes, and rotorcraft.

Current and Future Research Emphasis

Current Programs

Most of the examples of basic research listed in the previous section are ongoing programs in space and aeronautics. The continuing investigations in the space program utilize data returned from prior missions, with additional research flight missions scheduled for the near future. Among these are: Investigation of the terrestrial planets (Viking Extended Mission, Pioneer Venus); investigation of the moon (continued lunar sample analysis); and investigation of the outer planets (Voyager—the new name given to Mariner Jupiter Saturn '77). Also included are continuing investigations of the sun and sun-earth interactions (International Sun-Earth Explorer), high energy astrophysics (High Energy Astronomical Observatories A, B, and C), research on the interplanetary medium, and studies of the origin of life and the search for extraterrestrial life.

New or newly augmented projects or programs of special current interest are:

- Space astronomy investigations in the infrared, visible, and ultraviolet portions of the spectrum (i.e., International Ultraviolet Explorer, Infrared Astronomical Satellite, Space Telescope).
- Investigation of the environment of Jupiter (Jupiter Orbiter/Probe).
- Measurement of tectonic plate motion, leading to an understanding of upper crustal motion and earthquake dynamics, and eventually to the prediction of earthquakes.
- Ocean research on surface wind stresses, surface temperature, current velocity, global circulation, and surface wave height, ultimately of benefit to shipping, offshore exploration, and long-term prediction of weather and climate.
- The flight of a series of Applied Cloud Physics Laboratories (ACPL), permitting the study of cloud drop formation, growth dynamics, and kinematics in a near-zero-gravity environment.
- Basic research into transmitter and receiver componentry and characteristics in the "far-IR" frequency range (between visible and radio bands), to open up that range to communications and observation of cosmic processes.
- Investigation of novel lasers and their possible applications to remote sensing, power transmission, and measurement techniques.
- Research on intelligent, autonomous machines to provide the ability for machines to operate in an intelligent, learning mode of operation in space at great distances from earth without the need for realtime control from earth.
- Research on computational and experimental fluid mechanics to lead eventually to improved aircraft design.
- Research on composite materials to understand the factors determining fatigue and failures.

Near-Term Future

NASA's research program priorities for the relatively near-term future (next few years) are:

Physical sciences. To study planets, comets, asteroids, stars, nebulae, galaxies, quasars, and other sources of radiation in all wavelengths, with emphasis upon X-ray sources, UV and IR spectroscopy, and cosmic and gamma-ray sources; study the interaction of the solar wind and the magnetosphere; study the interplanetary medium; and determine the nature of solar variability.

Environmental sciences (planetary). To determine characteristics of the Venus atmosphere and determine the gravitational character of the planet; upgrade knowledge of Jupiter, Saturn, and their environments by acquisition of imaging, fields and particles, and composition data; and improve our understanding of Mars via continued analysis of data from Viking and other missions.

Environmental sciences (Earth). To conduct remote-sensing research for identifying and monitoring pollutant species in the troposphere and water bodies, especially for all-weather and day and night conditions; conduct remote-sensing research on monitoring the physical parameters of the ocean surface, using active and passive microwave radars; conduct research into those features of severe storms most readily identified by remote sensing technology; develop preliminary models of crustal inhomogeneities based on tectonophysics, magnetic field, and gravity field, etc.; and study the composition and structure of the upper atmosphere.

Life sciences. To study physiological changes in man and other organisms that would result from a gravity-free environment; and research for extraterrestrial life.

Engineering sciences. To increase fundamental knowledge of fluid mechanics and aerodynamics; establish basic understanding of noise- and pollution-generating processes resulting from aircraft operations; apply solid-state chemistry and

physics to an improvement in the operational characteristics of electronic and optical materials; investigate energy exchange processes among atoms, molecules, electrons, ions, and fields for use in energy conversion, lasers and their uses in science, and solar energy conversion; advance information and electronic sciences to provide improved data management at lowest possible cost; increase capability of engineering materials to withstand high temperatures to make possible development of efficient aircraft engines and space power systems; and gain a basic understanding of fiber-matrix composite materials.

Long-Range Future

NASA's research program priorities for the longer range future (next 10 years or more) are:

Physical sciences. To conduct further surveys of the sky in new wavelengths that will identify objects and phenomena in the distant regions of the universe; study these objects and phenomena at greater spectral and spatial resolutions; and develop detailed understanding of the physical processes in the Sun-Earth system and within the Earth's complex magnetosphere-atmosphere system.

Environmental sciences (planetary). To conduct detailed studies of the terrestrial planets and bodies, relating their history and condition to those of the Earth; extend our first-order knowledge to more of the outer planets and their satellites; and carry out reconnaissance of the smaller bodies in the solar system (comets and asteroids).

Environmental sciences (Earth). To conduct the space segment of a national climate program; understand and assess the contribution of individual climate elements to the climate picture; and monitor movement of major tectonic plates to an accuracy of a few centimeters per year.

Life sciences. To use the unique, gravity-free environment of space flight to further knowledge in medicine and biology by exploring basic physiological mechanisms in all living systems; and search for extraterrestrial life, and attempt to understand the formation and existence of life in the universe.

Engineering sciences. To provide the technology base for new aeronautical concepts; provide efficient means to transmit energy in space; provide autonomous systems for space exploration; develop technology base for major break-throughs in propulsion and space power systems; provide technology base for large-area systems for space missions; and advance information science to include computer-human interactions, artificial intelligence, and establishing and implementing the best use of computers.

Other Promising Areas

A number of other basic research areas appear to offer promise of achievements of some significance and potential payoff, but are not now being pursued as much as they might be and are not now planned for increased support in the years ahead. Chief among these are:

- Research on the fundamental physical and chemical processes involved in the remote sensing of atmospheric and water constituents and pollutants.
- Detection of strain buildup along extended faulted areas.
- Increased activity in propagation research in new, higher frequency bands to provide opportunities for wider band future satellite communication links with reduced interference.
- Search for other planetary systems.
- Search for extraterrestrial intelligence.

Organization and Management of Scientific Activities

Organization

The NASA organizational structure has evolved to meet changing national needs and program priorities. There are three major management areas at the Associate Administrator level. Two of these, the Associate Administrator and the Associate Administrator for Space Flight, are responsible for the R&D programs of NASA.

The Associate Administrator is responsible for programs in space science, space applications, aeronautics and space technology, tracking and data acquisition, and energy (jointly or cooperatively with ERDA). Also under his authority is the Office of University Affairs, which provides a modest level of funding to academic institutions or individuals at institutions for support of research. All of the basic research in NASA is funded by these programs, the greatest part by the space science and aeronautics and space technology programs.

The Associate Administrator for Space Flight is responsible for R&D programs in space transportation and in the operation of space transportation systems. Chief among the present programs are development of the space shuttle, the spacelab (by the European Space Agency, with NASA cooperation), and the interim upper stage (by DOD, with NASA cooperation). Other upper stages for the space shuttle are being developed by the private sector. All of these elements comprise the space transportation system, to be operational in the early 1980's. This Office is also responsible

for procurement of the presently available expendable launch vehicles and the study of advanced space transportation, habitation, and industrial systems. This Office funds no basic research *per se,* but supports basic research in its provision of space transportation. One class of expendable launch vehicles, that used to launch the Explorer satellites, is classified basic research for the purpose of NASA's report to NSF and OMB's special analysis.

The two preceding groups—the offices under the Associate Administrator and that of the Associate Administrator for Space Flight—fund all of NASA's R&D programs and provide headquarters-level management as here noted. The third major group, that of the Associate Administrator for Center Operations, is concerned with the implementation of the R&D program. Reporting to the Associate Administrator for Center Operations are 11 major field installations (and 5 geographically separate component installations). These field installations are charged with the conduct of in-house R&D and with the direction of out-of-house R&D funded by grant or contract. A small portion of the R&D program—chiefly research in the space and life sciences, is funded from and directed by appropriate headquarters offices, but the great majority of funds flow to the field installations. The 11 field installations, with their respective areas of basic research identified, are:

- Ames Research Center, Moffett Field, California. Basic research in life and engineering sciences, with major programs in aeronautics.
- Hugh L. Dryden Flight Research Center, Edwards, California. Basic research in engineering sciences, particularly in aeronautics.
- Goddard Space Flight Center, Greenbelt, Maryland. Basic research in physical and environmental sciences.
- Jet Propulsion Laboratory, Pasadena, California (a contract laboratory). Basic research in physical, environmental, and engineering sciences.
- Lyndon B. Johnson Space Center, Houston, Texas. Basic research in physical, engineering, and life sciences.
- John F. Kennedy Space Center, Kennedy Space Center, Florida.
- Langley Research Center, Hampton, Virginia. Basic research in engineering sciences, with major programs in aeronautics.
- Lewis Research Center, Cleveland, Ohio. Basic research in engineering sciences, with emphasis on aeronautical and space propulsion.
- George C. Marshall Space Flight Center, Huntsville, Alabama. Basic research in physical and engineering sciences.
- National Space Technology Laboratories, Bay St. Louis, Mississippi.
- Wallops Flight Center, Wallops Island, Virginia. Basic research in environmental sciences.

The field centers either conduct basic research in house or fund extramural parties by grant or contract to conduct basic research. The work is done in the broad program areas established by the program offices of headquarters, but a significant degree of autonomy to determine more specific basic research projects is delegated to the centers. The grants and contracts awarded directly from headquarters can be used to conduct research in areas not otherwise covered by programs directed by the field centers.

Management

NASA's research and technology program, including the basic research portion, is currently managed through "the RTOP system." The RTOP —the research and technology objectives and plans—is the key document in this management system. It is a concise statement of the justification, the objectives, the approach to be used, and the resources required to conduct a definitive piece of research. It is prepared by the field center in response to an annual statement of program objectives by the responsible headquarters program office. The RTOP thus serves as a basis for communication and negotiation between headquarters and the field centers. When approved by headquarters, it becomes a contract or agreement between a headquarters program office and a performing field center. Headquarters is obligated to provide the resources, and the field centers are required to execute the work (in-house or out-of-house) to fulfill the stated objectives.

Within the RTOP system, each field center—or each headquarters program office, in the case of direct funding of grants or contracts—uses a somewhat different system for detailed initiation, review, and evaluation of basic research activities or projects. However, they usually include the following elements:

- Proposals for basic research are usually initiated by the in-house or university researcher in response to broad agency objectives and funding guidelines or to specific solicitations or announcements of opportunity.
- These proposals are then evaluated by agency program managers with assistance or advice from external review boards or committees or other peer-review groups. The perceived importance or relevance of the task, the capabilities of the researcher, the quality of prior contributions, and the need for stability and

continuity of effort are primary factors of evaluation.

- Review and evaluation are obtained by periodic status reviews at the field centers or research sites by headquarters program managers, by extensive use of visiting committees or boards comprised of outside experts in the field, and by appropriate NASA senior management groups.
- Written reports that evaluate the importance and quality of the research are usually prepared for management attention.

At present, about half of the NASA funds expended for basic research are expended in-house—mostly for the conduct of basic research, but in part for the management of extramural basic research, as well. The balance goes to the conduct of basic research in industry, the university, federally funded research and development centers, and others. Many factors enter the decisions on whether to conduct a given research task in-house or out-of-house. Among those factors are where the "experts" reside; the need to establish or maintain "centers of excellence" in both Government laboratories and universities, where special facilities may be located; when a joining of Government and university or Government and industrial capabilities is desired; and when a new capability may need to be created. Such decisions are made on either a task-by-task basis, or by broad field of work. An overview by senior management is also periodically made to assure that a proper level and stability of support to the university community is obtained.

NATIONAL SCIENCE FOUNDATION

INTRODUCTION
ASTRONOMICAL, ATMOSPHERIC, EARTH, AND OCEAN SCIENCES
BIOLOGICAL, BEHAVIORAL, AND SOCIAL SCIENCES
MATHEMATICAL AND PHYSICAL SCIENCES AND ENGINEERING
RESEARCH APPLICATIONS
SCIENTIFIC, TECHNOLOGICAL, AND INTERNATIONAL AFFAIRS
SCIENCE EDUCATION

The overall NSF submission was coordinated by Theodore W. Wirths. Staff members who were mainly responsible for preparing and coordinating the submissions of the various directorates and offices included: Albert Bridgewater, Alan Grobecker, William Howard, Wayne Gruner, Thomas DeWitt, Eloise E. Clark, Thomas Ubois, R.R. Ronkin, Edward Weiss, Burl Valentine, Paul Herer, J. Arthur Jones, and Frederick W. Collins.

INTRODUCTION

NSF Mission

The opening words of the legislation that created the National Science Foundation (NSF) in 1950 declare that the first purpose of the act is "to promote the progress of science." The first prescriptions for the Foundation in that original charter are "to develop and encourage the pursuit of a national policy for the promotion of basic research and education in the sciences; and to initiate and support basic scientific research in the mathematical, physical, medical, biological, engineering, and other sciences. . . ." Other purposes are stated and other functions prescribed in the 1950 text and in amendments through the years, but by any standards, the commitment to the support of basic research and the promotion of the progress of science retain primacy in the Foundation's activities.

In accordance with this national policy more than 27 years ago and reaffirmed regularly by congressional actions since, NSF accounts for nearly 23 percent of total Federal support of basic research and for about 16 percent of total support from all sources, Federal and non-Federal, for basic research. Unique among Federal agencies in its dedication to basic research *per se* and its responsibility for future scientific research capability, the Foundation seeks to press fundamental scientific inquiry on all fronts. In responding to this dedication and this responsibility, it engages the efforts of scientists, including many just entering upon their careers, in more than 2,000 colleges, universities, and other research institutions. The diversity and numbers of scientists and institutions involved hold inherent promise that the research will be performed at a high level of competence. It is to such numbers and diversity that the high quality of basic research in the United States can be attributed in part.

The role of the Foundation in the advancement of basic research is enhanced by the fact that the more than 300 men and women who administer and staff its support activities in that area are themselves scientists who, being in close communication with the scientific community they serve, share in its excitements of exploration and discovery. There is a sharing, too, of the values that lend drive to basic research—the satisfactions of intellectual effort and intellectual achievement, and indeed of the kind of aesthetic experience that leads to the use of the word "elegant" as a precise term for scientific achievements of a rare sort.

Definition of Basic Research

Such excitements and satisfactions, which surely benefit basic research, are strong elements in the relationship between the Foundation and the scientists doing work under its auspices because their research can truly be called basic research—that is "systematic, intensive study directed primarily toward greater knowledge or understanding of the subject studied, rather than a practical use of this knowledge or understanding."[1] The open and competitive system by which researchers obtain support for their initiatives permits them to pursue their own ideas and press the very limits of their creativity.

Role of Basic Research

Freedom of inquiry in the basic research it supports is not in conflict with the Foundation's premise that basic research is a critical but often unrecognized form of economic investment. It is a lesson of long experience that basic research is a well-spring of technology that leads to the creation of new industries, improved services, more and better jobs and other important material benefits. Studies of the relation between basic research results and marketable applications of wide benefit to society are extremely difficult to carry through to conclusive results, partly because of the characteristic timelag between research and application and the unpredictability of often serendipitous events in arriving at application.

The investment aspect of scientific inquiry is recognized by the economist, Edward F. Denison, in a major study, "Accounting for United States Economic Growth 1929-1969." It is estimated that more than one-third of the growth in national income during the postwar period flowed from advances in knowledge, particularly in the sciences and the new technologies to which they gave rise. A comparable process may be discerned in the contributions of basic research to less strictly material "quality of life" benefits, particularly in the environmental and health fields. For a variety of reasons, the private sector lacks incentives to support basic research for which payoff may be distant or nonexistent. Thus, there is a fundamental realism in the funding of basic research through the Foundation.

In short, the bulk of Foundation support has been and continues to be focused on fundamental research conducted in the Nation's colleges and universities. This support thereby advances scientific knowledge and understanding, provides fruitful experiences for young people entering careers in science, and contributes to the economic and social well-being of the United States.

Apart from its support of individual scientists, the Foundation contributes substantially to achievements in basic research through a variety of other activities: Providing facilities and instrumentation, funding large national facilities and overseeing their management, maintaining surveys and analyses of levels of resources available to science, fostering improved dissemination of scientific information among scientists in the United States and its interchange with those abroad, and promoting programs in science education. In instrumentation, the continuous refinement of means of observation, measurement, analysis, data collection, and data reduction is a key factor in advances in basic scientific knowledge and understanding. Funding covers instrumentation aids ranging from bench-size items such as electron microscopes to the very large array of radio telescopes now under construction in New Mexico. The Foundation has responsibility for such large facilities as five major astronomical observatories, the National Magnet Laboratory, and the National Center for Atmospheric Research, and provides funds for the acquisition and operation of a flotilla of research vessels. The Foundation's surveys and analyses of the human, financial, and physical resources for research and development are a primary and continuing source of detailed information for the Federal Government and public and private R&D institutions, as well as for the Foundation itself in allocating its support, in performing its integrating and balancing function in the overall Federal support of basic research, and in its task of monitoring the "health" of the various disciplines and of the Nation's scientific enterprise as a whole. The Foundation's programs in support of science education seek to strengthen that effort at all levels, by improving science teaching and science learning, finding and encouraging scientific talent, and bringing understanding of science to society.

Examples of Basic Research

Significant achievements by researchers supported by the Foundation are reported in the subsections below describing program activities. Because the Foundation itself does not conduct research, measures of its achievements are found in the degrees of wisdom and alertness it demonstrates in

[1] Foundation definition of basic research.

responding to the needs and opportunities of science, in the competence of the researchers it supports, and in the quality of new generations of scientists helped to enter their careers.

Current and Future Research Emphasis

Advances in knowledge through basic research tend to open up further questions to be answered as do increasing complexities in national life. Some of the new questions being asked will be discussed in the program subsections. They show that basic research supported by the Foundation will be concerning itself with such diverse topics as enhancement of earthquake resistance in structures, laser chemistry, the origins of the universe, the physical processes governing climate, manmade contamination of stratospheric ozone, resource potentials of the ocean floor, the influence of deep sea organisms on the productivity of the oceans, the enhancement of biological fixation of nitrogen, preparation of new homogeneous catalysts, communications use of the channel capacity in the visible spectrum, development of materials resistant to corrosion and fracture, cell changes during growth and development, how enzymes work, the mechanisms by which genes are regulated, factors controlling cognitive development, mechanisms of sensory signal processing in the brain, and continued pursuit of subatomic particles.

Organization and Management of Research Activities

NSF is receptive to proposals for basic research in all fields of science, including mathematics, physics, chemistry, biology, behavioral sciences, astronomy, atmospheric sciences, earth sciences, oceanography, materials research, social sciences, engineering, computer sciences and information science, and multiple subfields.

Typical duration of an award period is one or two years, with renewal or extension possible. In special cases, to provide reasonable assurance of long-term support for continuing projects of high scientific merit, the Foundation may award support for up to five years.

Proposals usually are initiated by the individual scientists. Awards generally are made in response to both solicited and unsolicited proposals. Usually, awards for unsolicited proposals are made on a cost-sharing or jointly funded basis. Awards for solicited proposals may provide for payment of full costs, including fees.

Disposition of rights to data and inventions resulting from Foundation-supported research is subject to negotiation. Factors to be considered are the nature and purpose of the project and other factors involving the public interest and commercial positions of the awardees and any equities they may have. At a minimum, the Government will receive a royalty-free, paid-up license and, in certain circumstances, the right to require the licensing of others on reasonable terms.

Management Structure for Research Support Functions

At the top of the NSF structure are the Director and the National Science Board. (The law, in fact, says they are the Foundation). The Board is the policymaking body, and has 25 members including the Director ex-officio. The Director and Board members are appointed by the President and confirmed by the Senate for six-year terms. The terms of Board members are staggered so that the terms of one-third of the membership expire every two years.

The Deputy Director and four Assistant Directors are also appointed by the President and confirmed by the Senate. There are currently three other Assistant Directors who are appointed by the Director. Assistant Directors head the functional Directorates among which most of the work of the Foundation is divided. There are three Directorates primarily concerned with support of basic research, and which account for most of the research support in basic research discussed herein. Each is headed by an Assistant Director who is a Presidential appointee; they are Mathematical and Physical Sciences and Engineering; Biological, Behavioral, and Social Sciences; and Astronomical, Atmospheric, Earth, and Ocean Sciences. Some of the other Directorates, including the Research Applications Directorate, also include an amount of support for basic research in their programs.

More than 400 program managers and research administrators expert in their fields develop the program plans of the Foundation. The program managers assess the needs and opportunities in their areas, and in this process, draw information from professional societies, the National Academies of Sciences and Engineering, contacts with thousands of scientists across the country, members of the Foundation's program panels, and the thousands of *ad hoc* reviewers. They also gain a view of the patterns of Federal science support programs from their colleagues in other agencies.

A major role in the program development process is performed by the National Science Board.

The Board's assessments lead to recommendations for program emphasis, constraint, reduction, and reorientation, which are incorporated into proposed programs by the Director and the Foundation staff.

Recommendations and guidance from congressional oversight committees bearing upon the Foundation's program directions are taken into account in program development, which is also subject in some instances to congressional mandates. Recommendations of the President and the President's Science Adviser are likewise elements in the development process.

The Foundation's program is coordinated with research programs of other Federal agencies by interagency committees, frequent discussions among agency program managers and research administrators, and through the Office of Management and Budget.

A proposal for Foundation support is assigned for review and evaluation to the division or office having responsibility in the intended field of research. If it passes initial scrutiny, it is submitted to peer review. Peer review takes several forms in different directorates, but three forms account for nearly all review actions: *ad hoc* reviews; panel reviews; and *ad hoc* reviewers plus panels. In all of these cases, the peer reviews are advisory to the Foundation program officers, preserving the authority of program staff—and the Foundation—over the obligation of Federal funds.

Peer reviews strongly influence ultimate decisions on proposals. Care is taken that for a given proposal the reviewers possess relevant expertise, and, as a group, show fair distribution by geographical area and types of institution and do not include persons having a professional or personal relationship to the proposer which might affect objectivity. A program manager's award recommendation is subject to review at higher levels in his Division, if necessary, his Directorate; and if the size of the award requires, by the National Science Board. All grant awards are also given final scrutiny by an Action Review Board, which is a cross section of the Foundation's expertise. Applicants whose proposals have been rejected have access to a formal appeal process.

The following sections describe the work of the various directorates of the National Science Foundation in support of basic research. The material was for the most part prepared in the Directorates. Each adapted the material to its own particular role. For this reason the individual sections have not been recast into a standard mold.

DIRECTORATE FOR ASTRONOMICAL, ATMOSPHERIC, EARTH, AND OCEAN SCIENCES

AAEO Mission

The Directorate for Astronomical, Atmospheric, Earth, and Ocean Sciences (AAEO) supports basic research in selected disciplines to increase knowledge of the environment on Earth and in space. The overall objectives of the Directorate are to:

- Obtain new knowledge in astronomy and the atmospheric sciences over the entire spectrum of related physical phenomena.
- Provide a better understanding of the physical and chemical makeup of the earth and its geological history.
- Obtain further insights into the oceans' composition, structure, behavior, and resources, and examine the effect of human activities on the ocean environment, and *vice versa.*
- Advance knowledge of natural phenomena and processes in the polar regions.

Division of Astronomical Sciences

Goals and Objectives. The Division of Astronomical Sciences (AST) funds research aimed at increasing man's knowledge of the universe. Fields of research range from the properties of atomic and molecular systems in astrophysical environments to the overall structure of the universe. The constituents of the solar system, stars, interstellar matter, and galaxies are observed and described. Support for both theoretical and observational research and for instrument development is accomplished through basic research grants made primarily to universities. In addition, five national astronomical research facilities are supported through NSF contracts: National Astronomy and Ionosphere Center (NAIC), Arecibo, Puerto Rico, which conducts research in radio and radar astronomy and ionospheric physics; Kitt Peak National Observatory (KPNO), near Tucson, Arizona, which uses telescopes for observations at optical or infrared (IR) wavelengths; Cerro Tololo Inter-American Observatory (CTIO) in Chile, which provides advanced facilities for optical and infrared research in the Southern Hemisphere; National Radio Astronomy Observatory (NRAO), at Green Bank, West Virginia, provides the capability to study radiation in wavelength ranges between a few meters and one millimeter; and Sacramento

Peak Observatory (SPO), in New Mexico, which has facilities for research in solar physics and related fields of investigation.

The objectives of the astronomy grant programs are to:

- Understand the origin, evolution, and nature of the components of the solar system, including the sun, planets, natural satellites, comets, and the interplanetary medium.
- Understand the formation, evolution, and life cycles of stars. This requires knowledge of the production of nuclear and gravitational energy at all steps through the life stages of a star.
- Understand the dynamics and kinematics of stellar groups. These range in complexity from binary stars to star clusters and galaxies. This research involves the study of stellar positions, motions, and distances.
- Understand the composition, formation, interaction, and evolution of our Milky Way galaxy, the interstellar medium, other galaxies, and quasars through data acquisition, interpretation, and modeling.
- Provide state-of-the-art technology; design, construct, and improve the instruments used by astronomers to detect and analyze radiation at all wavelengths of the electromagnetic spectrum.

Examples of significant basic research support. Three significant preplanned projects include:

- Design, construction, instrumentation, and operation of 4-meter stellar telescopes at KPNO and CTIO.
- Upgrading of the NAIC's 1,000-foot radio/radar telescope
- Design, construction, and instrumentation of the 36-foot millimeter wave telescope and the observing program.

Six significant research thrusts in which a number of investigators participated (National Center staff and university grantees) include:

- Observation and modeling of quasars. Identification of optical quasars, measurements of increasingly large redshifts (apparent recessional velocities), verification by independent test of cosmological distances (which have revealed energy densities much greater than can be explained by the simple fusion of hydrogen), and observation of apparent rates of expansion of quasars much in excess of the speed of light.
- Detection, observation, and modeling of pulsars (neutron stars). Many discoveries of new pulsars, "glitches" (abrupt changes in pulse periods), discovery of the pulsar in the Crab Nebula, recording of pulsar pulse structure, and detection of pulsar in a binary system with possible black hole.
- Development of infrared astronomy. Development of efficient detectors, construction of specialized IR telescopes and modification of optical telescopes (e.g., KPNO 4-meter) for IR use observation of dust-shrouded regions (galactic center, stellar nurseries) in the infrared.
- Upgrading of optical telescopes at the national centers, universities, and private observatories with electronic image detectors and other instruments. Examples include the Wampler Image Dissector-Scanner and the KPNO Fourier Transform Spectrometer.
- Radio telescope receiver development. Parametric amplifiers, millimeter wave radiometers using cooled mixers, and maser amplifiers.
- Very long baseline interferometry (NAIC, NRAO, University-based antennas and other antennas supported by Federal agencies other than NSF). Development of the Mark I and Mark II recording systems for phasematching of antenna data, first satellite-linked experiment (1976).

Representative important publications based on NSF-supported research in astronomy. This list is compiled from suggestions from various sources. It is not based on a citation-index study and cannot be taken as a list of the 10 best or most important articles.

1. L. B. Robinson and E. J. Wampler, "The Lick Observatory Image-Dissector Scanner," Publications of the Astronomical Society of the Pacific, v. 84 (1972).

2. D. H. Staelin and E. C. Reifenstein, "Pulsating Radio Sources Near the Crab Nebula," Science, v. 102 (1968).

3. F. Pacini, "Energy Emission From a Neutron Star," Nature, v. 216 (1967).

4. C. A. Knight, D. S. Robertson, A. E. Rogers, I. I. Shapiro, A. R. Whitney, T. A. Clark, R. M. Goldstein, G. E. Marandino, N. R. Vandenberg, "Quasars: Millisecond-of-Arc Structure Revealed by Very-Long-Baseline Interferometry," Science, v. 172 (1971).

5. L. E. Snyder, D. Buhl, B. Zuckerman, P. Palmer, "Microwave Detection of Interstellar Formaldehyde," Physical Review Letters, v. 22 (1969).

6. R. L. Brown, M. S. Roberts, "21 Centimeter Absorption at $z = 0.692$ in the Quasar 3C 286," Astrophysical Journal, v. 184 (1973).

7. V. M. Blanco, J. A. Graham, B. M. Lasker, P. S. Ommer, "Optical Condensations and Filaments in the Northeast Radio Lobe of NGC 5128," Astrophysical Journal (Letters), v. 198 (1975).

8. F. J. Vrba, K. M. Strom, S. E. Strom, G. L. Grasdalen, "Further Study of the Stellar Cluster Embedded in the Ophiuchus Dark Cloud Complex," Astrophysical Journal, v. 197 (1975).

9. D. N. Page, S. W. Hawking, "Gamma Rays from Primordial Black Holes," Astrophysical Journal, v. 206 (1976).

10. D. N. B. Hall, "An Atlas of Infrared Spectra of the Solar Photosphere and Sunspot Umbrae in the Spectral Intervals 4040 cm^{-1} — 6700 cm^{-1}, 7400 cm^{-1} —8790 cm^{-1}," KPNO Publication (1976).

Current and future research emphasis. Current research problems in the astronomical sciences continue to be significant and exciting. Discoveries in recent years of objects such as distant radio galaxies, quasars, pulsars, and pulsating x-ray sources are indicative of the broad range of problems that require study and await explanation. Many of these discoveries are due to observations in new portions of the spectrum and improvements in the instrumentation being used to study the universe. Current emphasis in the Division of Astronomical Sciences is directed toward the study of these new objects which often exhibit extreme temperatures, densities, and pressures unattainable in terrestrial laboratories. However, the importance of traditional areas such as astrometry, stellar composition, and galactic structure has not diminished, and studies of this type continue.

At present, particular emphasis is being placed in the following four areas: (1) Development of improved detectors for existing telescopes; (2) studies of high energy processes in radio sources, quasars, pulsars, and x-ray sources; (3) studies of the early and late stages of stellar evolution; and (4) the determination of the composition and physical conditions in the general interstellar medium.

In the near future, emphasis will be placed on areas where we can expect large scientific returns for a modest application of resources. We will continue to explore the new and exciting wavelength regions of the spectrum where recent advances have been made. Support will be provided for millimeter and submillimeter wave instrumentation and observations, including the building of a three-element millimeter wave interferometer. More sensitive receiver systems at millimeter wavelengths will be developed to extend the capabilities of existing telescopes.

In the infrared, continued development of highly efficient optical and infrared detectors will be supported. This will include the two-dimensional arrays which provide much valuable spectral and brightness distribution information. Along with such array detectors, data acquisition and interactive processing systems must be developed and made available for a number of major observatories in the country. Infrared and optical interferometry is in its infancy and will be developed in the near future.

The valuable technique of very long baseline interferometry (VLBI) will receive increasing emphasis. The unequalled angular resolution of this technique is necessary for an improved understanding of energetic radio sources and quasars. A radio telescope of 25-meter aperture for VLBI observations at wavelengths as short as 1 centimeter is required in the Midwest to complement the currently available VLBI telescopes. Additionally, the present VLBI stations will require upgrading of their receiver systems and data acquisition and processing instrumentation. Studies will be carried out to determine the need for and design of a dedicated VLBI array. The Midwest dish will then be the first element of this dedicated array.

As rising levels of light and air pollution increasingly limit our current optical telescopes, a serious search must be undertaken to identify the optimum dark sky site for a major new astronomical observatory in the United States. Such a survey will require a number of years but can be carried on at a low annual cost. Simultaneously, the conceptual design studies for a major new large telescope (aperture of 1,000 inches or so) will be undertaken. The results of these studies and of the site survey will determine the timescale on which a major new astronomical center can or should be established.

The sun is of vital importance to man in terms of climate and as an energy source. In order better to understand the sun, the upcoming solar maximum in 1979-80 (which present indications suggest may be one of the lowest maxima in recent history) should be studied in great detail. This will require some modest support for new instrumentation, but primarily will involve increased support for investigators to obtain and interpret data during the period of the solar maximum.

To interpret and understand properly the data from many of the studies of stellar atmospheres and the interstellar medium, it is necessary that increased support of theoretical and laboratory studies of astrophysical phenomena be provided. The required increases will be modest compared to the data and understanding expected to emerge.

The construction of the "very large array" telescope will continue. By 1979, it will be the largest aperture synthesis radio telescope in the world. Its sensitivity will be 2 1/2 times that of the Westerbork array in the Netherlands (currently the largest), and resolution will be comparable to that of optical telescopes (0.2 to 2 arc sec). It will be used to produce maps of radio sources such as quasars enabling a detailed comparative study of these objects in both optical and radio wavelengths. It will be in great demand by university astronomers and support will be required for observations and interpretation of the data gathered.

Division of Atmospheric Sciences

Goals and objectives. The objective of the Division of Atmospheric Sciences is to increase knowledge of the behavior of the earth's atmosphere. The research that is supported may contribute directly to the solution or alleviation of atmospheric problems such as those associated with pollution from major industries, growing populations, and other societal actions that affect the atmosphere in various and subtle ways. There also is much to be learned about the origin of droughts and severe storms such as tornadoes and hailstorms.

Basic research support is provided on a wide range of subjects. Included are studies of the physics, chemistry, and dynamics of the earth's upper and lower atmosphere; the physical processes in the troposphere and stratosphere that will aid in understanding the general circulation of the atmosphere and the physical basis of climate; research on climate processes and variations; and research on smaller scale, shorter term phenomena leading to greater knowledge of weather processes. The National Center for Atmospheric Research (NCAR), at Boulder, Colorado, is a major research facility devoted to large-scale atmospheric research projects in cooperation with universities and other organizations.

Examples of significant basic research support. During the past 10 years, there have been several significant projects that deserve mentioning:

- Large scale dynamics came into their own due to the advent of earth-orbiting satellites that could observe the entire globe, and large high-speed, sophisticated computers that could handle large quantities of data needed for modeling problems. The most important result of that evolution is the Global Atmospheric Research Program (GARP). Two experiments have been held—one during the summer of 1974 (GARP Atlantic Tropical Experiment (GATE)), and another in February 1975 and 1976 (Air Mass Transformation Experiment (AMTEX)). Some articles relevant to GARP that have been funded through NSF support are:

Lorenz, Edward N. (1969): Atmospheric Predictability as Revealed by Naturally Occurring Analogues, *Journal of the Atmospheric Sciences, 26,* pp. 634-646.

Reed, Richard J., D. C. Norquist and E. Recker (1977): The Structure and Properties of African Wave Disturbances as Observed During Phase III of GATE. *Monthly Weather Review, 105,* pp. 334-342.

Norquist, Donald C., E. E. Recker and R. J. Reed (1977): The Energetics of African Wave Disturbances as Observed During Phase III of GATE' *Monthly Weather Review, 105,* pp. 343-362.

Shen, P. J. and E. Agee (1977): Kinematic Analysis and Air-Sea Heat Flux Associated with Mesoscale Cellular Convection during AMTEX 75 (in press). *Journal of the Atmospheric Sciences, 34.*

- Another project that embraces weather modification as well as cloud physics and mesoscale meteorology is the National Hail Research Experiment that began with support from NCAR, especially in the development of facilities. It has produced great advances in the understanding of the internal mechanisms of precipitation formation and the dynamics of storm systems together with an increased understanding of frontal systems. Unfortunately, the important question of which clouds to seed to lessen the hail damage to agriculture and other areas of society has not been answered. Among pertinent articles are:

Hoskins, B. J. and F. P. Bretherton (1972): Atmospheric frontogenesis models; mathematical formulation and solutions. *Journal of Atmospheric Sciences, 29,* pp. 11-37.

Browning, Keith A. and G. B. Foote (1976): Airflow and hail growth in supercell storms and some implications for hail suppression. *Quarterly Journal of the Royal Meteorological Society, 102,* 499.

- Magnetospheric studies in the upper atmosphere have been focused by the organization, planning, and beginning of the International Magnetospheric Study (IMS). The IMS is a coordinated international cooperative program to study key problems of the nearby space environment, that region controlled by the earth's magnetic field. The program is just beginning; however, the next few years should greatly improve our knowledge of the magnetosphere. Two important articles are:

Ahasifer, J. I. (1975): The solar wind-magnetospheric dynamo and the magnetospheric-substorm. *Planetary and Space Science, 23,* 817-823.

Roederer, J. A. (1976): IMS 1976-1979, New concepts in international scientific cooperation. *EOS, 57.*

- The chemistry of the stratosphere is becoming more important, particularly with the problems of ozone depletion and increasing concentrations of fluorocarbons and nitrogen oxides. A significant early series of measurements of great importance to the problems of supersonic transports (SST's) and fluorocarbons was made as early as 1971. Again, little is known of this area of the atmosphere and few observations are available. A key article in the field is:

Williams, W. J., J. N. Brooks, D. G. Murcray and F. H. Murcray (1972): Distribution of nitric acid vapor in the stratosphere as determined from infrared atmospheric emission data. *Journal of the Atmospheric Sciences, 29,* 1375-1379.

- Solar-terrestrial relations is another important area of research, especially since the apparent variations of solar activity may have a possible connection with climate and weather. At this point, only correlative information is available; however, with observations from the IMS and an increasing interest by competent scientists, progress should be made in the next five years. An important article on the subject is:

Eddy, John A. (1975): The solar constant and the earth's atmosphere. *Proceedings of the Workshop,* Big Bear Solar Observatory, 98.

Current and future research. The NSF's current support of atmospheric science focuses on five research areas:

- Mesoscale meteorology including GATE analyses
- Development of a complete paleoclimate record
- Measurement of winds by incoherent scatter radar
- Studies of the magnetosphere during the IMS
- Use of the newly developed millimeter wave radiometer to study profiles of minor species up to 80 km.

Over the next 3 years, FGGE (first GARP global experiment) and MONEX (monsoon experiment) analyses, mesoscale meteorology, atmospheric chemistry, IMS analyses, and studies of solar activity and solar terrestrial relations will emerge as major areas of research support.

Over the next 10 years, requirements for research on mesoscale meteorology will lead to a severe-storm and mesoscale experiment. In addition, climate studies and a magnetic cleft observatory to study the magnetic cusp will serve as the focal point for Foundation support. The magnetic cleft is a singular region of the magnetosphere at which the solar wind has direct access to Earth's atmosphere: it provides a unique environment for plasma physics studies, and for studies of the impact of energy deposition on the earth's atmosphere. The rate of deposition is sufficiently great that it is believed to be of significance to global scale atmospheric behavior.

Interagency coordination. Atmospheric sciences research has perhaps the best coordination mechanisms within the Federal Government. There are interagency committees that offer a forum for discussions of agency projects, national needs, and support of international programs. These interagency committees and the establishment of interagency project offices to carry out the tasks of various projects are the substance of the interagency consultation and coordination. These mechanisms apply also to basic research projects, applied research, and meteorological services.

International research. The Division of Atmospheric Sciences plans to continue to support projects in foreign countries. There are some instances where the only way that the work can be done is to have it supported outside the United States. International cooperative science programs are a major part of this Division's research support. These efforts have been successful because of the cooperative interaction between representatives of various countries and the fact that there have been effective international planning efforts. The biggest problems are usually political, and they have no real bearing on the science itself. Unfortunately, political aspects sometimes are determining. In future years, political aspects will become more important factors in atmospheric sciences programs, such as climate, because the results have an interaction with political, economic, and social problems.

Division of Earth Sciences

Goals and objectives. Research in the earth sciences is designed to increase man's understanding of the solid earth. Geology is currently undergoing a major revolution. Terms such as "sea-floor spreading," "global tectonics," and "plate tectonics," are now established. They refer to the components in a working model that account for most of the earth's major features and provide the means of focus on concepts that result in efficient study of the forces that slowly but continually change our planet. These forces result in earthquakes, volcanoes, mineral deposits, and sources of energy.

The plate tectonics model must be tested to define its limitations. Such activity is the main focus of the International Geodynamics Project (IGP), an effort involving scientists from some 45 nations. This project will terminate in 1979. Its successor is likely to be an international project that will concentrate on problems involving continental-to-oceanic-crust transitions. Meanwhile, the earth sciences program is continuing its support of projects associated with the IGP while phasing in some support for the initial research and planning needed for its successor.

Fulfilling maximum prospects of developing the resources of the planet requires a thorough understanding of the natural mechanisms that lead to the creation and concentration of ores and hydrocarbons. The prediction of natural hazards and their possible mitigation by artifical means similarly require that the underlying natural controlling forces be understood. Virtually all scientific methods employed in prospecting for economic deposits are based on the scientific understanding that

has been derived in geology, geophysics, and geochemistry over the past century, but the maximum rate of growth of such comprehension has undoubtedly occurred during the past decade.

Basic research in the earth sciences has taken advantage of substantial new technological achievements, such as the dynamic positioning of a drilling vessel, which is the basic tool employed in the ocean sediment coring program. Drilling in the deep oceans has provided a wealth of basic research contributions. Thus, a continual interchange between basic research needs and technological developments characterizes research in the earth sciences.

Examples of significant basic research support. Two fields of research in geochemistry (experimental petrology and field and isotopic studies of rocks) have yielded particularly impressive basic scientific dividends during the past decade.

- Experimental petrology. To understand the origin of rocks other than sediments, which constitute the crystalline part of the earth's crust, much effort has been in projects supported at several of our major universities. Examples are:

EAR 7620413, "Experimental Studies on the Origin of Plutonic Igneous Rock Series";

EAR 7620410, "Petrogenetic Links between Carbonatites and Kimberlites";

EAR 7300266, "The Role of CO_2 in Generation of Basalt in the Upper Mantle";

EAR 7422501, "Determination of Elastic Constants by Brillouin Scattering up to 100 kbar in a Diamond Anvil Cell."

Some of the most important papers recently published are:

Wyllie, P. J. (1966). Experimental studies of carbonatite problems: the origin and differentiation of carbonatite magmas in "The Carbonatites," p. 311-352. O. F. Tuttle and J. Gitlens, Eds. J. Wiley and Sons.

Huang, W. L. and P. J. Wyllie (1975). The influence of mantle CO_2 in the generation of carbonatites and kimberlites: *Nature, 257,* 297-299.

Ming, L. C. and W. A. Bassett (1975). Decomposition of $FeSiO_3$ into FeO and SiO_2 under very high pressure and high temperature, *Earth and Planetary Science Letters, 25,* 66-70.

- Field and isotopic studies of rocks. The Division of Earth Sciences has long supported studies of isotopic measurements of rocks, which are essential to understanding the age and responses to various sources of physical and chemical change in rocks. Examples are:

DES7424199, "Oxygen and Hydrogen Isotope Studies of Rocks and Minerals."

EAR7623153, "Field and Isotopic Studies of the Older Geologic History of the Southwestern Margin of North America."

Some of the more important publications in this field include:

Taylor, H. P. (1973). O^{18}/O^{16} evidence for meteoric-hydrothermal alteration in the Tonopah, Comstock Lode, and Goldfield mining districts, Nevada, *Econ. Geol., 67,* 227-242.

Silver, L. T., C. R. McKinney, S. Deutsch, and J. Bolinger (1968). Uranium-lead isotopic variations in zircons: A case study: *Jour. Geol., 77,* 721-758.

- The geophysics program of the Division supports a wide range of basic research involving the physical properties and dynamics of the planet. Examples of the most significant publications are:

Isacks, B. and Sykes, L. R. (1968). Seismology and the new global tectonics, *Journal of Geophysical Research, 73,* 5855-5899.

Isacks, B. and Sykes, L. (1969). Focal mechanisms of deep and shallow earthquakes in the Tonga-Kermadek region and the tectonics of island arcs, *Bulletin of Geol. Soc. of Am., 80,* 1443-1469.

Molner, P. (1969). Lateral variations of attenuation in the upper mantle and discontinuities in the lithosphere, *Journal of Geophysical Research, 74,* 2648-2682.

- Geology, which is the parent science in the Division of Earth Sciences, has played a continuous role during the past decade of scientific advances, although the recent spectacular successes have been more readily identified with geophysics and geochemistry. Recently, however, the geology program has contributed significantly by its support of the study of "ophiolites," which are portions of the deep sea floor that have been emplaced on the present continents by the process of obduction (tectonic overlayment), and related studies of mountain belt distributions resulting from the collision of continents and the ocean floor. Examples are:

DES 7306591, "Detailed Study of Portions of the Vourinos Ophiolite Complex, Greece"

DES 7201471, "Ophiolite Complexes and Related Rocks in the Northern Appalachians."

Among the most important publications in the general area are:

Dewey, J. F., and Bird, J. M. (1970). Mountain belts and the new global tectonics. *Jour. Geophysical Res., 75,* 2625-2647.

Morgan, W. J. (1968). Rises, trenches, great faults, and crustal blocks. *Jour. Geophysical Res., 73,* 1959-1982.

- Since 1968, NSF has supported the Deep Sea Drilling Program (DSDP) (Scripps Institution of Oceanography). The Joint Institutions for Deep Earth Sampling (JOIDES) provides sci-

entific advice to the project. This has been the most successful large-scale study of the earth ever attempted, and it has provided the basic results on which proof of continental drift and sea-floor spreading is based. Over 50 separate cruises have now been completed. To date, 36 volumes detailing concise results have been published. A wide range of current literature in geology, geophysics, geochemistry, and their marine counterparts is based on the results of the project.

Current and future research emphasis. Current earth sciences support reflects a continuing refinement of the implications of a mobile crust for the origin of earthquakes and the production of lateral variations in the structure of the earth's crust.

Identification of research priorities for the next decade can be made only in the broadest terms. The Division of Earth Sciences can, however, anticipate the development of massive scientific justification for an expanded Ocean Sediment Coring Program (OSCP) using technological advantages that could be provided, for example, by such a vessel as the *Glomar Explorer.* Such a drilling program would, in addressing the mysteries of the region between the true continent and typical ocean floor, find itself simultaneously providing the scientific basis for what may become the final great energy exploration endeavor left for man. Whether or not the vast fraction of the planet that is transitional between continent and ocean was formed under conditions suitable for hydrocarbon accumulation is a question of major significance for today's society. The Division of Earth Sciences anticipates support from the scientific community to obtain deep core samples from this region for a wide series of analyses involving many branches of the science. The Division also believes it essential to work closely with the Division of Ocean Sciences on the refinement of drill site selections which can be made only on the basis of an intensification and technological maturing of submarine geology and geophysics.

The continental drilling program, which is yet to be initiated, would occupy center stage in earth sciences research on the continent. Another major effort is the work of the Consortium for Continental Reflection Profiling. This should result in increased understanding of the continental basement structure and aid in the efficient selection of sites for deep holes to be drilled by OSCP. In addition, a substantial initiative will be required in the upgrading of instrumentation, particularly in the geochemistry program.

With the reservation that there is always the possibility that future trends can change drastically in response to exciting new concepts, maximum scientific returns from funding of research in the following fields (in addition to the expanded ocean drilling program) can be expected:

- Research in isotopic and high-pressure geochemistry related to the origin of ores
- Research aimed at improving understanding of processes involved in earthquakes
- Support of a large-scale seismic reflection profiling survey to determine the fine structure of the crust and upper mantle
- Initiation of support for the continental drilling program and an increase in studies of those parts of the continent that have resulted from interaction between continental and oceanic crust.

International research. The Division of Earth Sciences supports field work by U. S. scientists in several foreign countries as dictated by scientific priorities.

On a larger scale, the Ocean Sediment Coring Program has substantial foreign participation. Five foreign governments each contribute up to $1 million annually to the operating costs of the Deep Sea Drilling Program, in which the annual United States contribution is about $18 million. Foreign scientists participate in the formulation of scientific advice to DSDP and form part of the scientific parties during cruises of *Glomar Challenger.*

Whether problems materialize during international cooperative programs frequently depends upon relations between the scientists involved. Each new initiative in international research projects must be closely examined prior to making substantial commitments, including solicitation of advice from active U. S. scientists who have directly experienced scientific cooperation with scientists from the country involved.

Division of Ocean Sciences

Goals and objectives. The overall objective of the Division of Ocean Sciences is to improve man's understanding of the nature of the ocean, its influence on man's activities, and man's impact on the marine environment. This is accomplished through three major programs: Two basic research programs—one to support projects of individual scientists at the oceanographic institutions, the other to support a limited number of large, managed projects—and a program that provides for the acquisition and operating costs of the ships and other oceanographic facilities needed to carry out these research programs.

The Oceanography Section provides grants to individual scientists for developing fundamental knowledge about the oceans, their contents, and the sea floor. Investigations concentrate on these areas of study: Physical oceanography, marine chemistry, submarine geology and geophysics, and biological oceanography.

The International Decade of Ocean Exploration (IDOE) supports large-scale, multidisciplinary, international projects focused on the role of the oceans in climate, food production, pollution, energy, and natural resources, with considerable participation by nations around the world. These efforts are incorporated into four programs; Environmental forecasting, environmental quality, seabed assessment, and living resources.

Oceanographic Facilities and Support (OFS) contributes directly to these oceanographic research efforts by providing about 65 percent of the total support for 30 research ships and a number of specialized facilities which are scheduled on a shared-use basis. Based on its program of review and evaluation of academic fleet performance and material condition, OFS supports a continuing effort to upgrade the facilities necessary to sustain a healthy oceanographic research effort at the Nation's universities.

Five most significant projects over the past 10 years. Below are five projects concerned with the study of oceans:

- Physical chemistry of seawater, Frank Millero of the University of Miami. Dr. Millero, through his careful, well-conceived analytical and theoretical work, has provided the standard and foundation for present understanding of the physical chemistry of seawater.

Millero, F., 1974, The equation of state of seawater, *Journal of Marine Research*, 32.3, pp. 443-456.

- Climate Long-range Investigation Mapping and Prediction (CLIMAP). CLIMAP researchers have developed and applied quantitative techniques to the analyses of the paleoclimatic record contained in marine sediments. These analyses have allowed the reconstruction of the major elements of the earth's climate (sea-surface temperatures, ice extent and elevation, and continental albedo) 18,000 years ago, the maximum of the last ice age (publication 1). In addition, selective time series analyses of specific sediment cores have resulted in two other extremely significant findings. The first was that oxygen isotope variations in marine microfossils are largely a measure of global ice volume. Because of this, oxygen isotope measurements provide a very powerful and global time-stratigraphic tool for correlating the ages of marine sediments around the world, and provide an extremely important means of determining phase relations between various components of the earth's climate (publication 2). The second significant finding was that the major climatic changes on earth over the past 500,000 years appear to have been caused by changes in obliquity, precession, and eccentricity of the earth's orbit and axis of rotation (publication 3).

1. CLIMAP Project Members, 1976, The surface of the ice-age earth, *Science*, V 191, pp. 1131-1137.

2. Shackleton, N. J. and Opdyke, N. D., 1973, Oxygen isotope and paleomagnetic stratigraphy of equatorial Pacific core V 28-238: Oxygen isotope temperatures and ice volumes on a 10^5 and 10^6 year scale, *Quaternary Research*, V3, pp. 39-55.

3. Hays, J. D., Imbrie, J., and Shackleton, N. J., 1976, Variations in the earth's orbit: pacemaker of the ice ages, *Science*, V194, pp. 1121-1131.

- Faunal and trophic studies of intertidal communities, Robert T. Paine of the University of Washington. Dr. Paine pioneered modern ecologic studies of shallow water and intertidal environments using a manipulative experimental approach. His work over the past 10 years has resulted in a general redirection of such research and in the widespread application of his approach to a broad spectrum of shallow water habitats, and, more recently, to the deep sea.

Paine, R. T., 1974, Intertidal community structure: Experimental studies on the relationship between a dominant competitor and its principal predator, *Oceologia 15*, pp. 93-120. This publication is only an example. In 1974, Paine's previous publications in this research area were cited 133 times.

Four interesting projects currently in progress. The following four ocean sciences projects are currently in progress:

- Cyclonic gulf stream rings. This project is studying the generation, movement, and decay of very large ocean eddies that break off from meanders in the Gulf Stream. These eddies are to the ocean what hurricanes are to the atmosphere, and they may be a major component of the ocean's "climate." Researchers include Philip Richardson of the Woods Hole Oceanographic Institution and Andrew Vastana of Texas A&M University.

- Seismic studies of the oceanic crust and upper mantle. This project is developing and applying new seismic tools and field techniques to investigations of the structure and physical properties of the oceanic lithosphere and its flexure seaward of subduction zones. Manik Talwani of Columbia University is a major researcher in this area.

- Geochemical ocean sections (GEOSECS) study. GEOSECS is an international cooperative program involving geochemists from 14 U. S. universities. Investigators from Belgium, Canada, France, Germany, India, Japan, and the United Kingdom are participating in the GEOSECS program or are

carrying out similar programs coordinated by the United States. The U. S. program involved the occupation of 121 oceanographic stations in the Atlantic, and 147 stations in the Pacific. These stations were located along north-south survey tracks and generally coincided with the paths of bottom-water currents. Comparable work will soon begin in the Indian Ocean. The data are being used to determine the stirring and reaction processes in the deep sea, the interchange of material between deep and surface waters, and the exchange of water and gases with the atmosphere.

- Galapagos rift zone. Scientists at Oregon State University, Scripps Institution of Oceanography, Massachusetts Institute of Technology, Woods Hole Oceanographic Institution, and the U.S. Geological Survey are cooperating in a study of hydrothermal circulation of seawater through newly formed seafloor on the Galapagos Rift Zone. Bottom water at a temperature of 2°C circulates down into the oceanic crust, removes both heat and metals from the rock, and returns to the overlying seawater through vents on the seafloor. Using the research submersible *Alvin,* scientists in the program have recently sampled three of these vents. The discharging water of one vent had a temperature of 12°C and showed high concentration of silica, hydrogen sulfide, and other metals. Such hydrothermal circulation systems may provide a long-term control on the chemistry of seawater and are responsible for the formation of metal-rich sediments on the seafloor. Quite unexpectedly, large communities of organisms were found clustered around the vents. Some clams in these communities were as much as 10 inches across! It is not presently known whether nutrients or merely the elevated temperature of the discharging water supports these organisms.

Areas of future emphasis. The research priorities for the next 3 years are:

- Investigations of the chemical, physical, biological, and geological processes occurring at the deep-sea floor
- Paleoenvironmental studies of the recent evolution of the oceans, ocean basins, and global climate
- Increased application of manipulative field-experimental approach to ecological studies of a variety of marine shallow water habitats
- Dynamics of circulation, mixing, and transport processes in estuarine and continental shelf waters and in adjacent boundary currents such as the Gulf Stream
- Increased application of geochemical and geophysical techniques to understanding the structure and properties at the oceanic crust
- Physical oceanography of the equatorial Pacific in conjunction with the first GARP global experiment
- Expanded and interrelated studies of marine organic materials, biochemical processes, and surface reactions on particulate matter

For the next 10 years, the research priorities are:

- Structure and function of open-sea biological communities emphasizing the role of nekton (free-swimming aquatic animals)
- Physical processes involved in air-sea interactions with emphasis on large-scale interactions in the equatorial regions
- *In situ* marine chemical experimentation and manipulation
- Deep structure and geologic evolution of continental margins and the ocean basins
- Refinement of models of the general ocean circulation
- Determination of the driving forces for plate tectonics.

International research. Although the Division supports few research projects in foreign countries, many oceanographers from the United States conduct their basic research in the coastal waters of foreign countries. The major problem in conducting oceanographic research in foreign waters has been receiving timely clearance from coastal states to conduct research in their waters. These problems are likely to increase rather than decrease in importance over the next five years, particularly if the current "Law of the Sea" negotiations result in the kinds of requirements now being discussed as conditions for access to coastal waters. Additional problems include those associated with productive scientific collaboration between countries differing widely in resources and sophistication, and the difficulty many nations have in committing resources over long periods of time for extensive and costly research programs.

Division of Polar Programs

Goals and objectives. The Division of Polar Programs (DPP) supports basic research programs in both the Arctic and the Antarctic.

The goal of the Arctic Research Program is to extend environmental and resource-related research in the Arctic in cooperation with other Federal agencies, the State of Alaska, industry, and other countries, as necessary.

NSF has been assigned overall management responsibility for executing the national program for Antarctica within the context of the Antarctic

Treaty. The goal of the United States Antarctic Research Program (USARP) has been and remains the complete scientific investigation of Antarctica and of the surrounding oceans. From the beginning, emphasis has been placed on increased understanding of the role played by the antarctic ice sheets and the physical and chemical processes associated with them in phenomena of global significance. Included in these are geological, geophysical, meteorological, and oceanographic processes. The contemporary thrust of antarctic research is toward examination of significant phenomena, environmental and ecological relationships, and specific geological and geophysical problems. Particular emphasis is placed on basic questions as they relate to contemporary problems elsewhere in scientific research. The primary focus is on polar processes and their relationship to connected or interdependent processes on a global scale.

Examples of basic research. Basic research in the Arctic and Antarctic are discussed below:

- In the Arctic. The purpose of the Arctic Ice Dynamics Joint Experiment (AIDJEX) has been to obtain quantitative answers to basic questions on the thermal regime and dynamics of arctic pack ice. The main field experiment was finished in 1975 on the pack ice of the Beaufort Sea north of Barrow, Alaska. This was the culmination of four years of planning and pilot projects. A mathematical model has been developed to describe the dynamics of sea ice to a resolution of 100 kilometers in distance and 1 day in time. The model was developed primarily as a research tool to understand the underlying physical processes of the pack ice. Present forecasting methods do not account for stress in the ice or the influence of boundaries. If it can be validated, the AIDJEX model will allow these factors to be included, giving a more reliable basis for forecasting and other applications.

The AIDJEX model will also be valuable for climate studies since it will provide the basis for understanding the interaction of the polar pack ice with the global ocean-atmosphere system. Theories of the onset and waning of ice ages frequently include assumptions about the extent of sea ice cover; many models currently used ignore this part of the earth in climatic reconstructions.

- In the Antarctic. In austral summer 1967-68, a fragmentary fossil bone was discovered near Graphite Peak in the Transantarctic Mountains. The bone fragment was a portion of a lower jaw of a labyrinthodont amphibian and was the first record of an ancient terrestrial tetrapod in Antarctica. As a result of this discovery, plans were made for further searches in the Transantarctic Mountains in austral summer 1969-70. Researchers found more fossil bones at Coalsack Bluff. The majority of these proved to be the remains of the Lower Triassic reptile, *Lystrosaurus.* The discovery of *Lystrosaurus* made a marked impact on the scientific community. This was a reptile closely related to, if not identical with, *Lystrosaurus* of the Lower Triassic beds of southern Africa. *Lystrosaurus* had also been found in the Panchet Formation of peninsular India and in China. In austral summer 1970-71 a campaign was mounted in the Shackleton-McGregor Glacier area, and a large collection of fossils was obtained. This collection was significant because in addition to the *Lystrosaurus,* it contained the remains of advanced mammal-like reptiles, the genus *Thrinaxodon,* the little cotylosaur *Procolophon,* and the prolacertilian reptiles. In South Africa, *Lystrosaurus, Procolophon,* and *Thrinaxodon* occur together in the *Lystrosaurus* Zone, as does the genus *Prolacerta.*

The discovery of a *Lystrosaurus* fauna at Coalsack Bluff helped establish beyond any reasonable doubt that the antarctic continent was once a part of a larger Gondwana continent and was contiguous to Africa. The amphibians and reptiles that constituted this fauna were unable to swim long distances across deep oceans and must have spread by way of dry land. The fossils from Coalsack Bluff constituted perhaps the strongest and most definitive palaeobiological evidence to prove the reality of continental drift.

Studies have been conducted on how antarctic fishes avoid freezing in near-freezing, ice-laden sea water. This has included studies on the physiology and biochemistry of fishes in McMurdo Sound. Eight blood glycopeptides have been isolated from the dialyzed blood plasma of antarctic fishes. These glycopeptides are simple compounds composed of only two amino acids—alanine and threonine—and two sugar residues—galactose and N-acetyl-galactosamine. They occur in eight sizes; they are long, narrow molecules, unlike most other proteins and glycopeptides, which are globular. They possess many hydroxyl groups, which make the molecules soluble in water and allow them to interact with ice. On a weight basis, they are present at concentrations of 4 percent. In these fishes, the eight sizes are found in the fluids of the body cavity, heart, and eye. Only the small ones have been found inside the cells of the liver and muscle. It therefore appears that the small glycopeptides may play a role in preventing the cells from freezing, while all eight sizes function to protect the extracellular fluids from freezing.

Areas of interesting current support. Basic research is being supported in the Arctic and Antarctic, as discussed below:

- In the Arctic. The Greenland Ice Sheet Program is a cooperative effort of Denmark, Switzerland, and the United States to extract climatic records as far back as they have been preserved in the annual layers of ancient ice. Cores have been obtained from eight locations. Glaciologists, geochemists, and geophysicists are working to understand the general characteristics of the ice sheet and to deduce the successive climatic regimes since its formation. Plans are being made to drill a deep hole (3,000+m) to bedrock at a site in central Greenland where the bottom ice is predicted to be at least 400,000 years old.

The three-year Research on Arctic Tundra Environments (RATE) program in summer 1975 to develop understanding of dynamics interactions between grazing and tundra vegetation and of the biological controls for productivity in arctic lakes. The grazing and tundra vegetation study is based at Meade River near Atkasook, Alaska. The objective is to understand the feeding relationship and transfer of energy between life forms. The study has three parts. In the first, studies are made of the landforms, soils, vegetational communities, herbivore populations, and developmental patterns of vegetation after disturbance. The second part has studies of the physiological responses of the plants to physical conditions, particularly their water relations, photosynthetic capabilities, and nutrient allocations. The third part has experiments to test hypotheses on the impact of herbivory on individual plants and on vegetation and soils.

The RATE aquatic program is at Toolik Lake, 250 km south of Prudhoe Bay, Alaska, along the trans-Alaska pipeline route on the north side of the Brooks Range. There are four objectives of the aquatic program: (1) To develop an understanding of the role of predators and grazers in determining the biological structure of the communities one or more trophic levels below them; (2) to develop a comprehensive model of the processes limiting biological productivity in oligotrophic lakes on the Alaskan North Slope, particularly deep ones, such as Toolik Lake; (3) to collect baseline data from a North Slope lake in the vicinity of major construction activities and potentially subject to future recreational uses; and (4) to develop mathematical models that will help predict biological consequences of disturbances in North Slope lake and pond areas, including road construction, nutrient enrichment, oil spills, and reduction of fish populations.

- In the Antarctic. The Ross Ice Shelf Project (RISP) is a multidisciplinary effort to investigate the physical, chemical, biological, and geological conditions in the ice shelf, in the water mass beneath the ice, and in the soft sediments and bedrock at the bottom of the sea. It involves more than 70 people from 9 countries. The data obtained will be used to interpret the past history and the present conditions of this portion of Antarctica.

The drilling program will obtain ice cores and open and maintain access holes that will allow sampling of the water column, investigation of the ice-water and water-sediment interfaces, collection of aquatic biota, and sampling of the subsea sediments.

In addition to drilling activities, the geophysical and glaciological survey of the ice shelf was continued in 1976-77. The results have provided ice thickness, subice water depths, snow accumulation rates, and ice deformation data—all needed to enhance understanding of the dynamics of this major ice feature. Tidal measurements on the shelf and oceanographic studies along the shelf edge, using icebreakers, help define the interaction between the sea and the ice shelf.

A krill life cycle and ecology project continues, addressing biology and population dynamics, metabolic pathways, and other areas. Researchers have been able to sustain krill alive through several molting cycles. Concern about the exploitation of krill stocks arises from the absence of realistic data on density, dimensions, frequency, and distribution of krill swarms. Questions include: If man harvests krill on a large scale, what effect will this have on the recovery of whale stocks, or on the average annual harvesting of whales? Will man be competing with marine mammals? Will heavy exploitation of krill stocks disturb the normal balance in marine ecosystems? What might happen if overexploitation coincided with an unanticipated change in environmental conditions, and the krill population collapsed?

In 1976, representatives of 10 antarctic treaty nations, plus West Germany and Poland, met in the United States for a conference on the conservation of living resources of the southern ocean. The group reviewed the present knowledge of whales, seals, birds, squid, fish, and other organisms feeding on krill. The main recommendations of the conferees were:

1. Establish an international structure for management and conservation of antarctic living resources.
2. Establish an international project for obtaining basic data on all elements of the antarctic ecosystem.

Plans are being made to participate in the implementation of these recommendations.

Areas of future emphasis. In all science discipline areas, long-range projections of research priorities are, for the most part, continuations of existing programs. Slight expansions are projected during the next three years in a few areas. The most significant change is a major proposed expansion in the study of the living resources and oceanography of the southern oceans. Initiation of the West Antartic Ice Stream Project to determine whether or not that feature is in a state of stagnation or on the brink of a catastrophic collapse is planned as the Ross Ice Shelf Project draws to a close in FY 1979.

During the next decade, continued emphasis must be given to research on the living resources and oceanography of the southern seas. A major geological drilling effort in the Dufek Mountains is planned for the 1981-86 timeframe. Near the end of the West Antarctic Ice Stream Project, plans call for initiation of the Ronne Ice Shelf Project to be conducted in the pattern of the Ross Ice Shelf Project and toward the same general objectives.

Interagency consultation. In the Antarctic, present Federal policy requires other agencies to come to DPP for funding of research projects or for the logistics support with which to conduct their in-house supported research. Informal consultation is fostered by this Office and the other agencies interested in pursuing antarctic research. For example, there is the cooperative university-National Aeronautics and Space Administration-NSF support of the rocket and balloon studies at Siple Station in conjunction and in coordination with ionospheric sounding by the VLF antenna at that station. In addition to direct coordination, an attempt is made to utilize reviewers and utilize comments from specialists in these other agencies in the process of defining and implementing joint research activities.

In the Arctic, the Interagency Arctic Research Coordinating Committee (IARCC), chaired by the NSF, provides a formal forum for consultation and coordination of effort on research projects of mutual interest. This has worked about as well as the representatives from each agency collectively wish it to work. In some instances, this forum has provided a meaningful way for consultation and coordination; in others, it has not worked so well. In addition to, and probably more important than, the formal meetings of IARCC, is the fact that agency representatives soon get to know each other. This very quickly has led to an informal consultation and coordination of efforts among the agencies, more often than not, on a bilateral basis. The same mechanisms apply both for basic and applied research projects and other activities.

Support of research projects in foreign countries. The Division supports a few research projects in foreign countries, all of which have an extremely important basic research component. In fact, this is the major criterion by which foreign investigators are selected.

The major problem identified in connection with international cooperative research programs is a general tendency to expect the United States to assume the major funding responsibility. This is particularly true when major logistics and equipment support is required. There is a tendency for the other partners to keep all of their funds in scientific programs. There is a general unwillingness to provide even token amounts of money to support their logistics effort. In conjunction with this, however, they do wish to be equal partners in the decisionmaking and in sharing in the results of the activities the United States supports.

In the future, continued problems of this nature are anticipated. There tends to be an increasing awareness of national priorities, and with the decreasing amount of money available for science support, it may become increasingly difficult to fund proposals received from foreign countries in potential competition with U. S. investigators. In joint research projects with some nations, U. S. foreign policy certainly will be a major factor in the decision to carry out joint activities.

DIRECTORATE FOR BIOLOGICAL, BEHAVIORAL, AND SOCIAL SCIENCES

BBS Mission

The Directorate for Biological, Behavioral, and Social Sciences (BBS) supports basic research that seeks to augment knowledge and understanding of fundamental life processes, factors pertaining to man as an individual and as a member of society, and the behavior, organization, and development of human societies and other biological communities. A companion and interrelated goal of the Directorate's support activities is to develop and maintain research resources, complex data sets and analyses, innovative techniques, and advanced methodologies to be used for further research, both fundamental and applied.

The work of the Directorate is divided into four subactivities: Physiology, cellular, and molecular biology; behavioral and neural sciences; environmental biology; and social sciences. The research in these fields embraces natural and social phenomena ranging from the fundamental components of life, such as biomolecules, to the complex interactions of human life in groups as small as families and as large as multinational aggregations.

Examples of Basic Research

Given the scope of biological research supported by the Foundation and the extraordinary advances that have occurred during the past decade, a brief account must necessarily fall short of fully stating the significance of the intellectual effort and the interdependence of findings and results from which major advances developed. Areas of the field in which NSF support has contributed to advances of particular significance are:

- Molecular biology, including substantial refinement of genetic and biochemical mechanisms of inheritance, regulation of gene activity, and expression of gene products. Successful isolation of a repressor molecule, *in vitro* replication of biologically active viral DNA, reconstitution of active ribosomal subunits, isolation of a purified gene, synthetic assembly of a working gene from nucleotide building blocks, and many other advances in the late sixties and early seventies underlie the current use of recombinant DNA techniques.
- Structure and function of macromolecules, in particular enzymes, emphasizing subunit interactions and the role of ligand binding in mediating enzyme activity through small changes in the structure of the protein distant from the active site; higher order aggregations of macromolecules comprising cell organelles; deeper insights into the immune reaction and basic studies involving the formation of antibodies.
- Cell membranes and surfaces involving detailed studies on chemical composition, dynamic state, role in transport phenomena, neural transmission, function related to changes in cell shape, and locomotion.
- Plant sciences, especially primary processes in photosynthesis, CO_2 fixation, biological nitrogen fixation, chloroplast structure and function; land-water interactions of forest systems, tropical plants.

Expansion of basic research support in environmental biology. The general stimulation of biological research arising from advances in molecular biology was slower in these fields and funding had not kept pace with the biomedical research areas. Theoretical advances, an increasing awareness of the need to develop quantitative analytic methods for investigations of ecological problems, and the growing concern with environmental degradation and potential loss of renewable resources argued for the timeliness of the decision to strengthen the scientific base of information associated with the biotic world. The consequences are seen most conspicuously in:

- Selective feeding and ecological dynamics, especially the nature of the co-adaptation—morphological, physiological, and biochemical—of terrestrial plant species and the insects that feed upon them; also the ecosystemwide consequences of selective predation in aquatic habitats.
- Structure and function of ecosystems area, under which the four biome studies (grassland, eastern deciduous forest, northwest coniferous forest, and desert) initiated under the international biological program and the earlier Hubbard Brook study have accelerated the development of information in environmental biology and stimulated a new approach that relies heavily on collaborative efforts and the application of models for investigating ecological problems.

Behavioral sciences. Research in the behavioral sciences has received growing emphasis during the decade and provided information of substantial significance in a number of areas:

- Behavioral science research in archaeology, anthropology, and linguistics has led to broadened understanding of the origins of man; studies in experimental psychology and ethology have provided conceptual advances in understanding animal behavior; increased sophistication in the analysis of cognitive processes is yielding major gains in understanding the human intellect.
- Neuroscience has been marked by rapid development of research on the brain and nervous systems which has yielded many exciting developments: Greater understanding of the plasticity of the nervous system, specification of additional neurotransmitters, identification of opiate receptors and the associated endogenous enkephalin peptides, further understanding of the transduction mechanisms for incoming sensory stimuli. All add to a basic understanding of the nervous system and have future clinical implications.

Social sciences. An amendment to the NSF Act in 1968 explicitly included the social sciences among the scientific fields the Foundation is man-

dated to support. This provided important recognition and more visibility for disciplines such as economics, political science, and sociology. The NSF emphasis on fundamental research that illuminates basic social, economic, and political processes is illustrated in the examples cited here.

- Project LINK is a multi-investigator, multination effort which has developed the conceptual framework for integrating existing national econometric models and for implementing this system so as to obtain better predictions of world trade and of the balance of payments. Building from basic research, LINK forecasts and policy simulations are used regularly by the Departments of Treasury and Commerce, the Council of Economic Advisers, and the Board of Governors of the Federal Reserve System.
- Elasticity of input substitution in economics has been explored with "hybrid models" which incorporate features of input-output models and macroeconometric models. These models allow for the substitutability of one input for another and permit the simultaneous incorporation of changes in supply and demand. Much of the work with these models has focused on changes in the supply of energy and on the interplay between investment, technology, and production. This new brand of macroeconomic models should provide more realistic estimates of the production, employment, and inflationary effects of shifting inputs. They also contribute to a more complete understanding of how an economic system adapts to "shocks" and trends in the supply of commodities.
- Status attainment processes have been examined in a series of studies focusing on the factors that influence adult social status. These studies have clarified, with numerical estimates of effect, the role of parental status, educational achievement, and career beginnings as determinants of adult status achievement, and have also explored the consequences for social mobility of number of siblings, peer influences, tested intelligence, geographic migration, marital stability, achievement orientation, and other factors. More recent studies have compared the structural coefficients for different nations to explore the effect of societal features on the status attainment process in a comparative context.
- Social indicators are quantitative measures of the inputs and outputs that affect the quality of life. Research on social indicators has focused on previously neglected output measures and has highlighted the fact that there is not a very direct relation between input and output in most major areas of interest. For example, changes in the ratio of teachers to students are not accompanied by corresponding changes in academic achievement, and shifts in the number of policemen are not accompanied by corresponding shifts in the number of crimes. NSF grantees have provided a major part of the data for the volumes *Social Indicators 1973 and Social Indicators 1976,* issued by the Office of Management and Budget as a social report to the Nation and as a general background document for Federal policymakers.

Current and Future Research Emphasis

Five of the most interesting current biological, behavioral, and social sciences projects or program thrusts involving basic research are:

- Neuroscience. Man has long been fascinated with and challenged by the most complex and least understood of his bodily structures—the brain. A recent report to the President notes: ". . . the ultimate challenge to biomedical research, representing the very pinnacle of our understanding of the human organisms, lies in neurobiology." Technological and conceptual advances of the past two decades place the neurosciences on the threshold of being able to respond to this challenge. Tissue-culture approaches for studying neural tissue *in vitro,* research using simple invertebrate systems with identified neurons, and revolutionary new techniques for mapping nerve pathways are rapidly accelerating the understanding of brain mechanisms. Research problems in the neurosciences are attracting gifted scientists who have contributed significantly in other areas, and increasing numbers of young scientists are directing their research and careers toward neuroscience problems.
- The river continuum project. This project in environmental biology promises to enhance our understanding of stream ecology. The project is unique in several ways: (1) It is seeking a model for predicting continuous change in salient variables across a range of stream sizes up to sizeable rivers; (2) it is comparative by its design—simultaneous studies using exactly the same procedures are conducted in four contrasting geographic areas—eastern Pennsylvania, Michigan, Idaho, and Oregon; and (3) the third phase of the study brings all of the team members together for a concerted analysis of the best,

undisturbed river of any size in the continental 48 states—the Salmon River in Idaho. This phase marks an approach to investigating a single large river system different from any previously attempted and should provide significant generalizations about stream ecosystems.

- Cell biology. The new burst of research activity in modern cell biology is particularly looking toward an understanding of the interaction and regulation of molecular processes in eukaryotic cells. The research is primarily in the area of genetics, developmental and human cell biology. Studies in genetics include chromosome organization and genetic controls in higher organisms, animal virus research, and plant cell biology as well as strong programs in bacterial and phage genetics. Developmental biology includes cell adhesion, genetic basis for differentiation in higher organisms, fertilization, and plant cell culture. In the human cell area the structure and organization of genetic material and the intracellular regulation of protein synthesis are emphasized.
- New insights on unemployment. The traditional image of the unemployed stresses a labor pool seeking work, with a consequent decline in wages. It is now evident that current unemployment includes a large component of persons on "temporary layoff" who do not respond in accord with the assumptions about the unemployed which underlie traditional economic models. An employee on temporary layoff does not seek substitute employment but simply waits to be recalled to his job. Such layoffs constitute such a dominant component of the current fluctuations in unemployment rates that they seem to be responsible for certain puzzling features of economic indicators (for example, relatively high unemployment with no decline in wages). Identifying this fundamental change has stimulated research that promises to increase our understanding of how the economy works and that should assist in formulating improved Federal policies.
- Political consequences of advanced industrialization. A varied set of studies now underway explores how political institutions in advanced industrial democracies have changed and how the resulting political processes have adapted to such change. Among the studies in this general class is an investigation of industrial conflict that examines crossnational differences and trends in labor organization and in which statistical models are being developed to explain fluctuations in strike activity. Another study in this category explores how class voting changes with changing circumstances, emphasizing the role of shifting party strategies. Studies in this general vein promise to provide information about the workings of contemporary political institutions, point to inadequacies in theories based on earlier modes of organization, and provide new perspectives on processes of social change.

Research priorities in the biological, behavioral, and social sciences include the following:

Physiology, cellular, and molecular biology. Research priority areas in physiology, cellular, and molecular biology for the next 3 to 10 years include: Plant cell biology and physiology; mechanisms of photosynthesis and nitrogen fixation; plant and animal virology; somatic cell genetics; gene expression; structure and interaction of chromosomes, and parts of cells; mechanisms of enzyme activity and protein structure; structure and motion of membranes, ribosomes, and cells; research on large animals; and advanced instrumentation for study of biological molecules and components of cells.

Behavioral and neural sciences. Research priorities for the next several years include substantial increases for behavioral and neural sciences. Specific priority areas are anthropological research collections, access to technology for archaeological dating, equipment and facilities, and human and animal developmental behavior.

The Foundation and professional societies are working on plans to arrest the continuing deterioration of irreplaceable anthropological research collections and to increase access to technologies for dating archaeological discoveries.

Opportunities for rapid scientific progress in the behavioral and neural sciences are dependent on increased utilization of computer hardware and software. The recent ability to delineate the complex interconnections of the brain makes computer-assisted anatomical reconstruction essential. By 1980, microprocesser technology is likely to reach the point of routine use for collection and analysis of data and adjustment of parameters while an experiment is in process. By 1981, techniques adapted from physics—e.g., nuclear magnetic resonance—will be used more extensively by neuroscientists interested in receptor dynamics.

Research analyzing human and animal behavior during development provides a special opportunity for emphasis. Cognitive development and social and emotional development in children will receive special attention. Field studies of social behavior will be stressed, with a particular emphasis on comparing field assessments of human and nonhuman social organizations. The genetic and hormon-

al determinants of behavior also will be emphasized. Research on human memory, learning, concept formation, and other cognitive processes shows great vitality and these are priority areas.

Social sciences. Research priorities within the social sciences for the next 3 to 10 years will continue to emphasize basic research in economics, efforts to understand social and political processes in advanced industrial societies, and a continuing effort to develop social science data resources. Emerging areas of high priority research include political economy, family decisionmaking, complex organizations, and human environments.

Research on political economy will emphasize understanding the impact of governmental and nonmarket decisionmaking on the economy, and the effects of economic factors on political and other nonmarket decisions. This work will entail the development and testing of models integrating a more varied set of factors than the more traditional economic models.

Studies of family decisionmaking are moving toward more rigorous and more realistic theoretical models but remain handicapped by data limitations. A substantial investment is expected in further theoretical development and in the production of data pertaining to such decisions as family size, labor force participation, residential location, and household consumption.

Research on complex organizations will emphasize internal organization and decisionmaking processes, interaction with other organizations, and the influence of such organizations on public life and on the lives of individual participants. Some studies include governmental bureaucracies, with emphasis on predicting decision outcomes as a function of the constraints and conditions under which governments operate.

The study of human environments focuses on human modifications of environmental conditions, the impact of environmental change on human settlement and land use, and on "environmental perceptions" (what people perceive to be desirable or undesirable settings), factors associated with variations in such perceptions, and the impact of such perceptions on migration decisions, population concentration, and corporate location decisions.

Environmental biology. Research priorities in environmental biology for the next 3 to 10 years will continue to build on the new information and recent developments in ecosystems studies, tropical and population biology, and physiological ecology.

Studies in the biological regulation of lake ecosystems will emphasize collaborative research projects on key sites. Recent small research project findings are leading to large scale approaches to understand systemwide effects.

While the initial biome studies have provided a general understanding of the energetics of ecosystems, they also found evidence to suggest, for example, that individual species or groups of herbivores exert an inordinate control over this productivity. Furthermore, it appears that the period of active growth in certain plant species may control the growth of neighboring species. Evaluation of these effects will be emphasized.

Recent data provide a sounder theoretical and experimental basis for investigating the relationship of spatial variability on ecosystem stability in response to physical or biological perturbations. Strengthened knowledge on the role of spatial-temporal heterogeneity is essential to the development of optimum strategies for reforestation and wildlife management.

Cultivated systems are taxonomically simple and relatively easy to manipulate. Since these systems pose ecologically interesting and socially important challenges with respect to pest management and maintenance of long-term productivity to crop species, they will be utilized to provide a test system for enhancing basic knowledge.

The complex and relatively little-known humid tropics are the sites of some of the most innovative and revealing research in systematic biology, ecology, and ecosystem science. Preliminary study of tropic systems often has revealed that the grand generalizations derived from the better studied temperate systems do not apply.

Surveys of primary gene products (proteins) in natural populations have revealed significantly more genetic variability than would be predicted by current evolutionary theory. Research will be directed toward an understanding of the biological significance of mutations and their maintenance in populations.

Mathematical population theory will utilize new techniques, developed by statisticians and engineers to study animal populations. Power spectrum analysis and bifurcation theory are two examples that are now being usefully applied to studies of the growth of plants in a fluctuating environment and to data for cycles of insect abundance.

Promising or vital research areas not now supported. The Foundation is the primary source of support for basic research in the social sciences and in environmental biology. Funding levels in both are relatively low and are scaled, historically, to individual project support. In such circumstances, it becomes exceedingly difficult to provide support for large-scale data resource needs, or collaborative efforts in the social sciences, or providing equipment to environmental

biologists who are increasingly dependent on quantitative methodologies and analytical approaches in their investigations.

The research programs in the behavioral and neural sciences have an unusually broad conceptual base, and at present there are no promising or vital subareas of basic research that are not receiving some support. However, responsibilities in these fields are growing coincident with the tractability of problems. Many pressing needs cannot be met, especially those that require relatively substantial investments and dependence on sophisticated instrumentation.

Physiology, cellular, and molecular biology carries a major role in support of basic research in the plant sciences. Until the level of effort can reach more nearly optimal levels, augmentation in this field should continue. The molecular biology staff is particularly receptive to instrumentation development and adaptations that improve sensitivity and resolution in the interest of providing refined analyses of molecular structure. The effort is costly and inadequately supported (e.g., synchrotron radiation, neutron scattering, etc.).

Organization and Management of Research Activities

Project support procedure. Basic research projects are commonly initiated by the principal investigators. However, the staffs play a vital creative role by feeding back to the scientific community the information on major research requirements or unaddressed problems that they acquire as a result of the peer review process and attendance at scientific meetings and workshops. This feedback takes the form of informal discussions with the scientific community encouraging particular kinds of proposals, preparing responses to preproposals or concept papers, and convening workshops or conferences. For example, the biome projects and the integrated pest management project were identified as appropriate research topics at a workshop of American biologists convened to consider the possibilities for U. S. participation in the international biological program (IBP).

Trends in support of basic research. Biological research has changed completely since World War II, as a consequence of the new approaches and depth of understanding of biological phenomena that arose in the main from combined advances in biochemistry and molecular genetics. By now all subdisciplines have been touched and, with rare exceptions, leading research is analytic as opposed to descriptive. A second salient characteristic is the "fuzzing" of disciplinary boundaries—as approaches and methodologies from many disciplines are brought to bear on the solution of a given problem. The challenge of research problems in biological and behavioral sciences increasingly entices scientists from the physical sciences and mathematicians to these fields.

Consequently, the cost of research in biological and behavioral sciences has accelerated rapidly. In addition, highly individualistic efforts that were characteristic of researchers 30 years ago have given way to substantial collaborative efforts on complex problems. It is now most common for a scientist to pursue research in association with groups of students or senior colleagues. Support patterns have lagged in adjusting to the new requirements—primarily because resources have not kept pace with the advancing technology, nor with the general change in style of work.

In the social sciences, Federal support of basic research in universities (excluding psychology) was virtually nonexistent immediately after World War II. Since the early 1950's, the Foundation's commitment in these areas has grown progressively, but the total level of support remains quite low. Concomitant with the expansion of Foundation support for social science research has been a change in the nature of social science, especially an increasing utilization of mathematical and statistical methodologies in the empirical exploration of interrelated variables. With rising levels of knowledge and sophistication, access to extensive data sources has become a major requirement for the conduct of social science research.

The development of adequate and quantifiable information often requires major investment to support a group of scientists, e.g., social indicators, the electoral study, project LINK, etc. A second more recent and growing trend is seen in the move toward interdisciplinary approaches within the social sciences. The interface areas—political economy, socioeconomics, etc.—often give rise to new insights and major advances in understanding of social institutions and processes.

DIRECTORATE FOR MATHEMATICAL AND PHYSICAL SCIENCES AND ENGINEERING

MPE Mission

The program of the Directorate for Mathematical and Physical Sciences and Engineering (MPE) is designed to support research that will augment knowledge and understanding of:

- Mathematics and computer science
- The most fundamental laws of physics and chemistry
- How those laws are reflected in the properties and behavior of materials
- The basic principles of engineering, and limits to exploitation of those principles.

In pursuit of these goals, the Directorate conducts more than 40 subprograms in which research ranges from the quest for the ultimate fundamental particles to investigating the role of gravity in the evolution, structure, and fate of the universe. Additionally, funding for instrumentation and for existing, new, or improved facilities serving the disciplines involved in its programs constitutes an important part of the Directorate's support of basic research. In some cases—for example, in gravitational physics—it is not easy to draw a sharp line between progress in instrumentation and the research itself. The Directorate's activities in providing instrumentation and facilities will be described in some detail in the course of this discussion, in close relation to significant projects in actual research and in program initiation and development.

Examples of Basic Research

Below are some significant projects involving basic research.

Discovery of a charmed baryon. Physicists have announced the discovery of a "charmed baryon," a subatomic particle, which gives scientists a deeper insight into the basic structure of matter. The findings add support to the view that matter such as that found in atomic nuclei is composed of basic constituents known as "quarks" (fractionally charged particles). Up until recently the effects of only three types of quarks have manifested themselves, but a fourth type referred to as the "charmed" quark is required to explain the latest experiments.

"Charm" is an attribute or behavioral characteristic which, like electric charge, is additive. Although difficult to destroy, charm is not completely indestructible. Over very long periods, it is possible for charm to disappear owing to the action of the weak interactions—weak because they take so long to act. As a result charmed particles are long lived. Longevity is their distinctive characteristic over other particles of this class.

The discovery of the baryon by physicists from Columbia University (supported by NSF), and from Fermi National Accelerator Laboratory (Fermilab), the University of Illinois, and the University of Hawaii supported by the Energy Research and Development Administration (ERDA) is believed to confirm the presence of charm in nature. The "baryon" mass of 2.26 billion electron volts, its long lifetime before disintegration, and its final products of decay exactly fit expectations based on the four-quark picture.

The Columbia-Fermilab-Illinois-Hawaii team intensified its search for charm following the discovery in November 1974 of the J or Psi particle. The J/Psi was presumed to be made of a quark carrying a unit of positive charm and an antiquark carrying a unit of negative charm.

In the combination of the J/Psi particle the net charm carried is zero since the charm of the quark is annulled by the negative charm of the antiquark. Although the J/Psi and similar states discovered shortly thereafter supplied strong supporting evidence to confirm the reality of charm, it was necessary to find particles in which a charmed quark combines with one or more of the three other types of quarks that do not carry charm so there is no neutralizing effect.

It was not until the finding reported by the group of scientists from Columbia University, University of Hawaii, University of Illinois, and the Fermi National Accelerator Laboratory that this latest link between observation and prediction had been made. The basic combination of quarks forming charmed baryons has been found. Physicists are confident that in addition to these lowest mass charmed particles a rich spectrum of others awaits to be discovered.

The question of the existence of fractionally charged particles (quarks). Evidence for a fractional charge less than that of the electron has been reported. The smallest known electric charges in nature are those of the electron and proton, each of which has a single negative or positive unit of charge respectively. Such charges balance out each other in atoms, the simplest being the hydrogen atom with one proton for a nucleus and one electron in its shell.

Fractional charges are associated with the "quark" theory, which postulated quarks as the basic building blocks of matter to explain some of the anomalies turned up in particle physics research. According to the theory, quarks would have either one-third or two-thirds of an electron charge. The discovery of a fractional charge therefore suggests that quarks may actually exist. The "discovery" of a fractional charge is tentative and is subject to verification by other scientists. The funding of efforts to verify the discovery will be an ongoing activity of high priority for the Physics Division of the Foundation.

Laser chemistry. An organized effort is being made to support this area so that the unique capabilities and opportunities provided for chemistry by lasers will be realized as soon as possible.

Lasers are creating a revolution in fundamental research on chemical reactions. They can be used to prepare reactants in very well-defined initial energy states; they can selectively put energy into reactants in very well-defined ways (i.e., atoms and molecules can be selectively "heated"); they can be used to detect reaction products in very particular energy states and in very low abundances. They can also induce effects not ordinarily found in chemistry, due to the intense radiation fields they provide. From these possibilities new experimental opportunities are developing and the understanding of chemistry is enhanced. Thus, a new experimental technique is providing entry to entirely new areas of both experiment and theory.

Heterogeneous catalysis. This area will be closely coordinated with wide-ranging research in surface physics and surface chemistry.

The area of heterogeneous catalysis continues to occupy a position of high priority not only because of its vital importance to the chemical process industry, but also because of the complex nature of the scientific and engineering problems associated with it, the rich promise of breakthroughs and the high potential of applying the methodology to other areas such as enzyme technology.

Work is being supported that probes the nature of adsorbed surface species, using established, as well as developing, analytical tools. In response to the problems and needs generated by industrial work to develop new catalysts and novel ways to exploit known catalytically active agents, most of the research supported is systematically carried out under realistic conditions approximating those used industrially.

The study of specific classes of reactions such as oxidation, reduction, and reforming, as well as specific important reactions such as the water-gas shift and methanation reactions, are currently under way. In almost all cases the underlying mechanisms are being worked out with the ultimate objective of predicting catalytic behavior such as reactivity and selectivity and of designing catalysts, both chemically and physically.

Homogeneous catalysis. This area is receiving systematic emphasis and is building on the base created through prior support and stimulation of inorganic chemistry.

The core of a homogeneous catalyst is a transition metal atom. The complete catalyst complex comprises the transition metal and several coordinatively bound chemical groups or ligands. Basic research conducted in this area may have dual significance in that the results also have the potential for immediate industrial application. This area was designated as energy-related and special funding for it was made available in FY 1975 via the Foundation's energy-related general research program. Although no special funding is now provided for homogeneous catalysis, the area nevertheless continues to receive special attention in the funding of workshops and conferences on the subject. The synthetic inorganic and organometallic chemistry program has been actively involved in organizing a series of international workshops in homogeneous catalysis. The first one was held in Italy in 1976; a second in Japan in September 1977; and a third in France in November 1977. The fourth and fifth in the series involving the United States, Australia, and the Soviet Union are currently being planned.

Systematic improvement and refinement of research on gravity and gravitational interactions. Within the United States more than 85 percent of the funding for university-based research in gravitational physics is currently provided by the Foundation. This degree of concentration, a result of the Foundation's unique mission to foster the development of basic research, makes it the world's leading agency for support in this field.

The nature of gravitational physics underwent marked change in the past few years. Ten years ago, general relativity was largely the province of mathematicians searching for idealized solutions to complex questions. Now, the field is dominated by theoretical physicists, astrophysicists, and experimental physicists working on problems overlapping the frontiers of current research from astronomy to elementary particles. Over the past decade, gravitational physics has evolved from dominance by theoretical research to an area with a healthy experimental-theoretical mixture.

In the search for gravitational radiation, the sensitivity of present antennas has advanced four orders of magnitude in the past four years. As researchers now phase out poly-crystalline metal bars used at room temperature and conclude a switchover to massive, cryogenically cooled dielectric single-crystal bars, we may expect to see a

gain of another five orders of magnitude in antenna sensitivity during the next five years. The outstanding future problem to be tackled in this instrumentation development will be to produce a corresponding increase in the sensitivity of transducers coupled to the improved antennas.

Core (pure) mathematics. In the period from World War II to the mid-sixties, the U.S. mathematical research community grew from one of modest stature on the international scene to one of unquestioned preeminence. It has been a major achievement of the Foundation to have maintained intact the research capability built up then during the past decade, which has been a time of exceptional budgetary stringency and economic uncertainty for both educational institutions and government when virtually all support of core mathematics by other Federal agencies has ceased.

Initiatives in Research

In some fields, advances in research supported through this Directorate can be attributed in significant part to initiatives in programing and in the cultivation of existing fields where special needs or opportunities were discerned. Some examples are:

Establishment of a program of basic research in computer science. One of the outstanding technological achievements of the 20th century has been the development of the computer. Spurred by the demands of that technology, a new scientific discipline has emerged with its roots in abstract logic, mathematics, linguistics, and engineering—the discipline of computer science. The Foundation has established a program of basic research in this discipline.

A major area of active research in computer science is abstract complexity theory. Modern technology has given us more powerful computing devices at lower cost. Complexity theory concerns the classification of solutions to problems in terms of computational resources such as the time and memory space they require. Much of this research involves finding better algorithms, proving or disproving the existence of efficient algorithms, finding good approximation algorithms for hard problems or determining the "average" behavior of algorithms that appear intractable in the "worst case." Rapid progress has been made in this field in recent years.

Research in computer science and computer engineering requires computing and computers. Careful consideration shows many instances of research that require computing facilities or other research equipment dedicated to the research task at hand. The advent of minicomputers in recent years has made this an attractive option in terms of cost and effort and led to the decision by the Foundation to encourage the development of experimental research by providing dedicated instrumentation.

The phrase "intelligent systems" denotes computer-based systems that have some of the characteristics of intelligence. Relevant areas include pattern recognition, pattern generation, knowledge representation, problem-solving, natural language understanding, theorem proving, and others that relate to the automatic analysis and handling of complex tasks. Basic research in these areas has been supported by the Department of Defense (DOD), the National Institutes of Health (NIH), the National Aeronautics and Space Administration (NASA), and NSF, but recent shifts in research interests by DOD, NIH, and NASA have reduced the support available from these sources by several million dollars a year. The Foundation is now increasing its participation to protect the vitality of this research which has always been considered the most difficult but potentially one of the most important areas of computer science.

Surface science. The last several years have witnessed enormously increased activity in the field of surface science by chemists, physicists, and materials scientists. The study of surfaces has broad implications for catalysis, corrosion, surface-active electronic devices, and materials failure. Recently, the advent of new experimental techniques such as low energy electron diffraction, Auger electron spectroscopy, high resolution ion and electron microscopy, and photoelectron spectroscopy has revolutionized the prospects for understanding surfaces at a level of sophistication not previously possible. At the same time, many theorists, utilizing modern theoretical and computational techniques, have become involved in interpreting the results of the experimental investigations. This has also led, at major research centers, to the formation of collaborative groups of surface researchers, often from different academic disciplines and employing complementary surface-sensitive techniques. Considerable progress is currently being made toward the fundamental understanding of the properties of idealized surfaces and of simple molecules adsorbed on them. However, there is also increasing effort on more complex systems having more direct implications for technology, particularly in the field of catalysis. The relatively underemphasized area of interfaces, which bears on intergranular failure in structural materials, has also assumed increased activity and importance.

Rejuvenation of inorganic chemistry. The Foundation has provided special funding for this area. The effort has laid a basis for today's advances in the area of homogeneous catalysis research. Inorganic chemistry was already experiencing a resurgence in the early 1960's when the Foundation decided to give this area of chemistry special atten-

tion. Among the supportive activities have been national and international conferences and workshops on selected topics such as bioinorganic chemistry and organometallic chemistry (an area recognized recently with two Nobel prizes).

Structural chemistry. Special effort was made during the 1960's to provide support in this area. This research led to the development of the theories, computational algorithms, and instrumentation (e.g., computerized x-ray diffractometers) that now provide the basis for structure determinations of macromolecules such as proteins, enzymes, and DNA.

Emphasis has been placed on the development of knowledge about the geometry of individual molecules and about the influences of bonding and of environment on the arrangement of atoms within molecules. Studies of the solid state have utilized x-ray diffraction; support has led to the design of automated diffractometers and to the development of theories and computational methods necessary to interpret results. For complex molecules such as proteins and DNA, this affords a primary tool for the determination of how the molecules are constructed.

Synchrotron Radiation and Submicron Structures Research

The relationship between the establishment or upgrading of major facilities and the confident projection of resulting advances in research provides the basis for large projects in this Directorate in the fields of synchrotron radiation and submicron structures. Examples follow:

Development of a major coordinated program using synchrotron radiation. Synchrotron radiation refers to electromagnetic radiation produced as a byproduct of the operation of high energy electron accelerators. This source of high intensity radiation provides a powerful new tool for research on the properties of matter, including biological materials. NSF has provided support for synchrotron radiation facilities, but the installations now supported are not able to meet the user demand at the present time and certainly will not be able to handle the projected future demand. A study conducted under the auspices of the National Academy of Sciences addressed present and future needs for synchrotron radiation facilities and recommended immediate commitment to the construction of a major new facility as well as the expansion of the existing facilities as soon as possible. In response, the Foundation and ERDA worked out a coordinated plan for expanding the United States capability over the next decade to help meet the national need.

The FY 1978 budget of the Foundation provides funds for the enlargement of the Stanford Synchrotron Radiation Project (SSRP). Also in the FY 1978 budget are funds to expand the capability of the Wisconsin Synchrotron Radiation Center (SRC) by replacing the current workhorse, Tantalus I, with a larger, more powerful storage ring. The project will require $2.93 million and 2.5 years to complete. The FY 1978 budget for ERDA provides funds for the construction of a major new synchrotron radiation source at the Brookhaven National Laboratory. This construction project is expected to cost $24 million over a four-year period and will complement the NSF facilities.

The exploitation of these new, as well as the existing facilities, by the provision of research support for users of the facilities will be an area of major emphasis in the coming years. Since FY 1975, the Foundation has provided funds for the operation of the center at the University of Wisconsin as a user facility.

Synchrotron radiation is emitted by the relativistic electrons moving in a circular path through a magnetic field. The radiation is extremely intense, covers continuously a wide range of the electromagnetic spectrum, is highly plane polarized, is well focused, and is pulsed on a nano-second time scale. Tantalus I generates radiation from 60Å through the visible, which is used in many ways including photoelectron spectroscopy of solid surfaces, and absorption spectroscopy of gases. Particularly noteworthy results include the development of angular resolved photoemission spectroscopy from solid surfaces, which gives unique information about the orientation and energy dependence of the surface atom electronic states. This has allowed scientists to characterize more positively surface atoms and adsorbed atoms. Many new users of the source are becoming active in this area, which should bring significant progress in the study of surfaces.

Expansion of research on submicron structures. Facilities will be provided to university research groups for fabricating a wide range of submicron structures and for studying their properties and limitations. Such research holds vast implications for basic physics, crystal growth, catalysis, materials science, and biomedicine. There are potential applications of results in integrated circuitry and other areas of microelectronics.

A National Research and Resource Facility for Submicron Structures is being established, with Cornell University as the host institution, to foster research on methods for building submicron structures and to encourage expansion of the science base needed for submicron engineering; to provide a facility where research workers with different types of science or engineering backgrounds and from many different institutions can build experimental structures, devices, and systems needed in

research that involves submicron dimensions; and to open a center of expertise in submicron structures design which will serve as an information resource for the research community.

The facility will provide techniques for building structures of submicron dimensions and for analyzing the materials problems unique to submicron dimensions. In addition to facilities for electron beam lithography, x-ray lithography, Auger spectroscopy, and low energy electron diffraction, there will be basic research related to these techniques.

Both permanent staff of the host institution and visiting staff from other universities and industry will carry on research in fabrication techniques and in the problems related to the ultimate limitations of the dimensions of electron devices.

Facilities and Instrumentation

It was noted at the beginning of this section that support for facilities and instrumentation is among the most important activities of the Directorate for Mathematical and Physical Sciences and Engineering. Of special interest, considered by the Directorate to be among the most significant basic research projects it has supported in the past 10 years, are the examples described below.

Broadened responsibility for facilities for physics research. The Foundation has assumed support of major areas of physics research formerly supported by DOD or the Atomic Energy Commission, such as the elementary particle physics groups at Columbia University, University of Chicago, and Stanford University, and the nuclear physics group at the University of Maryland. Two particle accelerators of novel and very efficient design—the Cornell Electron Synchrotron and the Indiana Separated Sector Cyclotron—have been completed and placed in operation.

Assumption of responsibility for the ARPA Interdisciplinary Laboratories. In mid-1972, NSF assumed responsibility for the Interdisciplinary Laboratories (IDL) program previously supported by ARPA, the Advanced Research Projects Agency of DOD. Since then, four new Materials Research Laboratories (MRL's) have been initiated, and two of the inherited MRL's are in the process of being phased out.

The concept of thrust research has been developed, wherein two or more faculty members, often from different disciplines, work together toward common objectives. Efforts have been developed in areas such as mechanical properties, fracture, fatigue of metals, surfaces and interfaces, amorphous materials, etc., each of which requires both broad and in-depth approaches.

As a result of this, and other managerial changes, a good balance between materials science and engineering has been achieved, and undue duplication of effort has been eliminated. The MRL's now present a well-coordinated national program.

Assumption of responsibility for the National Magnet Laboratory. Responsibility for primary support of the National Magnet Laboratory (NML) at MIT was assumed by the Foundation in FY 1971. The laboratory had been initiated in 1960 by the Air Force Office of Scientific Research (AFOSR) as a national center for the production and use of high magnetic fields in scientific research; by 1971 that Office found it difficult to justify continued support in terms of its defense mission. As a unique national facility the NML has three major, related objectives: (1) To develop, operate, and maintain the most advanced magnet systems; (2) to provide unique magnet research facilities to visiting scientists; and (3) to carry out in-house basic and applied research using high magnetic fields. Since 1971, the visitors program has been expanded to involve some 75 users of the high-field facilities, including collaborative programs with NML staff and upgrading and improvement of the wide variety of high-field water-cooled magnets comprising the facilities. In a joint project with the Netherlands Government, a hybrid magnet consisting of a superconducting coil with a conventional water-cooled insert was recently designed, constructed, and successfully operated at a record field (300 Kilogauss). A high homogeneity superconducting magnet is currently under construction which will make possible nuclear magnetic resonance studies of biological molecules with higher resolution than is now available. The in-house research program has developed considerable, and often unique, strengths in magnetism, high-field superconductivity, magneto-optics, and plasma physics. The plasma physics work, in particular, achieved major experimental improvements in magnetic confinement for fusion and led to major, independent support from ERDA.

Chemical instrumentation. The Foundation very early recognized the value of advanced instrumentation to research in chemistry and as early as 1957 recommended awards for instrumentation to assist chemistry departments in the pursuit of research. Instrumentation grants received increased emphasis throughout the 1960's until 1968 when $4,300,000 was provided as a line item in the budget. In 1972, a decision was made to devote an increased portion of the general allocation of the Chemistry Section to instrumentation support and this support has been provided both for departmental instruments and for specialized supplementary equipment for individual investigators. Instrument grants have been awarded to educational institutions in all 50 States and the District

of Columbia, and through 1976, more than 850 departmental grants were made, totaling $30,800,000, along with more than $20,000,000 in institutional contribution. This program has also been responsible for aiding the development of new types of instrumentation that have opened large and exciting new areas of chemistry.

Looking Ahead

A most important unsolved problem in fluid mechanics remains that of turbulence. Within this area of research, large-scale coherent structure is most important; that is, turbulence represented by vortices whose characteristic length scales are of the order of the characterizing length scales for the flow generation. In spectral representation terms, one refers here to the portion of the turbulent energy spectrum with wave-numbers less than the wave-numbers normally associated with the peak in the energy spectrum.

In this range of wave-numbers, the turbulent motion controls phenomena such as the diffusion of momentum and the diffusion of scalar quantities such as temperature. Vortex dynamics of these length scales in turbulent flows is very poorly understood; yet such knowledge is essential to the understanding of diffusion processes especially under conditions where shear and stratification are present. Development of new experimental techniques and instrumentation have given new life to this very old but little understood dynamical process, and pursuit of research in this area will be emphasized in coming years.

Priorities in basic research are difficult, maybe even dangerous, to attempt to establish, given the unpredictable nature of future discoveries. About the best that can be done is to identify areas of emphasis based on the most promising research directions presently perceived. These have for the most part been dealt with in preceding sections, but some additional promising areas are: Theory of nonlinear waves; study of oscillating chemical reactions; study of electronic and structural properties of liquids; study of the transport and other properties of systems with two or more material phases; analysis of large, complex, manmade dynamic systems; study of relationships between mechanical properties of materials and their chemistry and internal structure (e.g., crack propagation, stress corrosion, hydrogen embrittlement); providing added computational capability for theoretical chemistry; increasing work on "intelligent systems"; providing dedicated instrumentation for computer research; and supporting fuller utilization of existing elementary particle accelerators.

RESEARCH APPLICATIONS DIRECTORATE

RANN Mission

The Research Applications Directorate (reorganized into "Directorate for Applied Science and Research Applications," February 6, 1978) was established in 1971 to bring the resources of science and technology to bear on selected important national problems. Its origin goes back to a 1968 congressional amendment to the 1950 charter of the Foundation, an amendment specifically allowing the support of "applied" research as well as basic research. Establishment of the Directorate came as a decisive step in an evolutionary process, begun in 1968, for the introduction of work in research applications as a clearly defined part of the Foundation's research support activities. With its establishment, the Directorate formulated the phrase, "Research Applied to National Needs," to emphasize the focus of its program and fostered use of the acronym RANN to give the new undertaking a ready identification. While its activities look primarily to research applications, the Directorate not unexpectedly finds need to support for its program purposes a significant amount of basic research—an estimate based on fiscal 1977 put the level at 35 to 40 percent of the RANN total—and has summarized the reasons in this comment:

> Basic research is usually supported by RANN when fundamental knowledge concerning specific phenomena is needed to reach the problem-solving stage; thus, RANN programs usually involve a mix of both basic and applied research, which varies depending on the problem area.

In the following discussion of the Directorate, research activities primarily applied in nature were excluded from consideration.

Examples of Basic Research

Ten of the most significant projects involving basic research carried out by the Research Applications Directorate are:

Airborne contaminants. For several years, RANN has supported research within its "Chemi-

cal Threats to Man and the Environment" program aimed at identifying, characterizing, and quantifying contaminants produced from atmospheric precursors of manmade and natural origin. The following projects are examples of the significant knowledge that is being gained in this area:

- "Sources, Transformations, and Chemical Nature of Atmospheric Pollutants", Glen Gordon, University of Maryland. Although the project is devoted mostly to the characterization of particulates emitted by pollution sources, it has included a significant program of homogeneous gas reaction kinetics. Fundamental rate constants have been measured for a number of chemical reactions involving many natural and pollutant species, as well as short-lived intermediates. These include species such as sulfur dioxide, nitric oxide, nitrogen dioxide, ozone, the OH and HO_2 radicals, and certain hydrocarbons. At least 18 of these determinations can be attributed to RANN support. The measurements have played a role in the national effort to understand plume chemistry, smog-chamber simulations, and the chemistry of the troposphere and the stratosphere.
- "Study of Chemistry of Airborne Particulates", T. Novakov, University of California, Lawrence Berkeley Laboratory. This award supported a study of the application of photoelectron spectroscopy (ESCA, electron spectroscopy for chemical analysis) to the identification of molecular species in the suspended particulates of polluted air. It was shown that carbon (soot) particles from combustion sources catalyze the oxidation of gaseous sulfur dioxide to some form of sulfate on the carbon particle surfaces. This previously unrecognized chemical process is now believed to contribute to the burden of hazardous particulate sulfates in polluted air.

The nature of the initially formed sulfate was investigated by reflectance infrared spectroscopy. It was determined not to be sulfuric acid, a bisulfate, metallic sulfate, or ammonium sulfate. It was concluded that it exists as doubly charged sulfate anions held on positively charged sites on the carbon surfaces. The discovery of the carbon-catalyzed oxidation of sulfur dioxide suggests that the control of airborne sulfate pollution may depend in part on controlling carbon emissions.

Screening tests for mutagenic chemicals. The development and evaluation of new tests for carcinogenic and mutagenic chemicals are important research objectives. The bacterial test systems which are developed and generally accepted are useful but they alone are not definitive. It is imperative that other lines of testing be pursued, especially in mammalian systems. Under NSF sponsorship, Dr. T. C. Hsu at the University of Texas has succeeded in showing that several widely used anesthetic gases, suspected of causing cancer and birth defects in operating room personnel, do in fact cause chromosome damage in the mammalian test system under development, although they were negative in bacterial test systems. This new test system showed that the number of chromosome breaks (a traditional measure of chromosome damage) was not increased by these chemicals, but that the chromosomes failed to separate properly and thus normal cell division was halted. The chemicals were assayed for mutagenic effects in three different cell lines by several techniques. The new technique allows the usual counting and characterization of chromosomes to be done but also allows observations of disruptions of the elaborate cell division or mitotic system employed by mammalian cells. In animal cells, precise segregation of chromosomes between daughter cells is imperative; otherwise, the resultant cells will be genetically unbalanced. This can lead to adverse effects on the whole system, e.g., mutagenicity, carcinogenicity, birth defects, or death of the cell. Improper segregation of chromosomes in these cells can lead to aneuploidy, i.e., an abnormal number of chromosomes, in the daughter cells. It is known that many spontaneous abortions and birth defects are associated with aneuploidy. Also, many cancer tissues are aneuploid. Therefore, chemicals that cause segregational errors may be teratogens and carcinogens but not necessarily mutagens. The chemicals that disrupt cell division are referred to as "mitotic poisons." These "mitotic poisons" constitute a group of chemicals (which have been neglected) with potentially serious effects on human health.

Nonlinear earthquake behavior of structures. The University of California, Berkeley, has been supported to study the fundamental dynamic behavior of structures and structural components during earthquakes, in both the linear and nonlinear ranges. Such basic research was needed to improve the engineering understanding of how various structures respond to the highly complex dynamic loadings caused by earthquake ground motions. As a result of such efforts, precise mechanisms of lateral forces, and shear and moment transfer between structural components and joints have been established. Mathematical modelings of the dynamic motion of structural systems have been developed. Methods of characterizing the energy absorption capability of structure during various stages of the earthquake excitations have been accomplished and developed. Engineers are now in a better position to predict the inelastic response of structures subjected to seismic inputs

and to design improved earthquake-resistant structures.

Earthquake behavior of fine grained soil. Through a grant to Cornell University, basic research has been conducted into the dynamic behavior of fine grained soils during earthquake excitations. Basic results which have been accomplished are: (1) A fundamental theoretical model for strength changes of fine grained saturated soils subjected to repeated loads; (2) an evaluation of the influence of loading frequency on the behavior of undrained fine grained soils; and a theoretical model for the influence of undrained creep which has been formulated and evaluated by tests; and (3) the development of a model for the long-term drained effects of load repetition on fine grained soils. Such results have significant impact on improved building construction, submarine landsliding, transportation facilities, and general construction activities.

Research on reinforced concrete material. Fundamental research has been conducted by Cornell University on the shear transfer in thick-walled reinforced concrete structures under seismic loading. The research involved the fundamental behavior of the concrete in transferring the internal shear forces carried by the longitudinal steel, the stirrup steel, the concrete cracked section, and the compression zone of the concrete. The shear transfer mechanism for static loads as well as cyclic loads was investigated to develop an understanding of the transfer action. The investigation developed a new concept of the transfer mechanism through the cracked interface of the particles with a better understanding of the action and the role of the longitudinal steel and the stirrup steel.

Ground motion studies. Several fundamental studies have been undertaken by academic researchers aimed at improving the basic understanding of earthquake ground phenomena with various geological and seismological conditions.

A versatile earthquake model has been developed by researchers at the Massachusetts Institute of Technology based upon consideration of shear cracks with finite cohesive forces propagating and skipping past the fault barriers. This model can explain a variety of fault or ruptured zone effects in the earth, including fault segmentation and rockbursts, ripples in seismograms which cannot be explained by path effect, and departure of scaling law of seismic spectrum from that based on similarity assumption.

The University of California at Berkeley has studied the stochastic characterization of ground motion and has developed synthetic means to generate analytically artificial earthquake motions in terms of random waves and energy pulses compatible with actual data. Three-dimensional stochastic representations of earthquake ground motions have been developed which provided a reliable basis for explaining real behavior of ground responding to seismic waves and transfer of ground motion forces to the structures.

Fire research. As part of its fire research program (recently transferred to the U.S. Department of Commerce), RANN supported a project at the University of Utah Flammability Research Center to develop analytical procedures that would better characterize the nature of the combustion processes of polymeric materials with respect to smoke generation and determine the physiological and toxicological consequences resulting from human exposure during smoke-producing combustion. The research resulted in an animal model for determining the relative inhalation toxicity under fire stress conditions. The model permits simultaneous evaluation of physiological parameters (blood, central and peripheral nervous system, and respiration) and behavioral aspects for determining survival response. It is the most advanced model available and could form the basis of new testing standards. An example of its usefulness is illustrated by the identification of a highly specific toxicant generated in combustion of a particular fire-retardant urethane foam. As a result, it appears to be unwise to use phosphorous-containing fire retardants in combination with low-molecular-weight adducts of trimethylolpropane.

Inadvertent weather modification. RANN has supported research to delineate the mechanisms whereby, and the extent to which, an agricultural region modifies its own climate, and an urban area modifies its surrounding weather, precipitation, and aerosol. Some fairly basic knowledge has been generated in the following areas:

- Cloud physics. Gaseous and particulate emissions from urban-industrial areas result in altered concentrations and size distributions of cloud active nuclei and modified cloud microphysical and precipitation physics processes. Urban areas in general (University of Chicago) and specific fossil fuel power plants (University of Washington) do not produce significant amounts of ice-forming particles; in fact, there is some evidence that pollutants may inhibit ice formation on natural nuclei. Sulfur gases undergo conversion to small particles which quickly reach detectable sizes. Urban and industrial areas are prolific sources of these small particles (University of Wyoming, University of Chicago), and plumes of these particles are often coincident with plumes of sulfur gases. With continued growth, these particles reach sizes where they can nucleate cloud drops (CCN). Concentrations of such particles are maximized down-

wind of urban areas (University of Chicago). These particles are associated with the development of a stable haze (University of Chicago) which forms during serious air pollution episodes and results in a widespread restriction of visibility (University of Wyoming) and a reduction in solar radiation reaching the surface (Center for Environment and Man). Unusually high concentrations of very large CCN are also observed downwind of cities (University of Chicago). The modified CCN concentrations result in modified cloud droplet populations which extend several urban diameters downstream (University of Chicago). Although the bases of urban clouds are usually higher than surrounding rural clouds (Illinois State Water Survey), radar detection of the first precipitation echoes occurs lower in the urban clouds (University of Chicago), presumably from the urban-industrial CCN, although the observations connecting these effects remain to be made.

Boundary layer dynamics. The altered surface features in an urban area cause a reduction in evapotranspiration and an alteration of surface heat storage, resulting in a warm, dry urban boundary layer (University of Wyoming). This effect is combined with alterations in surface roughness features to change the airflow characteristics of the urban boundary layer. Combined observations of the airflow and thermal structure of the urban boundary layer using instrumented research aircraft (University of Wyoming), dual Doppler radar (National Oceanic and Atmospheric Administration (NOAA/WPL)), and balloon soundings (Illinois State Water Survey) provide new insights into thermal perturbing influences on boundary layer airflow. Convergence and divergence patterns are driven by warm (heat island) and cold air anomalies (University of Wyoming). During the daytime, the convergence patterns may take the form of a vertical roll circulation (NOAA/WPL). The net boundary layer convergence into the urban heat island approaches 10^{-4} sec^{-1} and may result in the local deepening of the boundary layer by several hundred meters (University of Wyoming). At night, the convergence into the city appears as intermittent flow, and the urban influences produce anomalous low-level maxima in the vertical wind profiles (Illinois State Water Survey).

Current and Future Research Emphasis

The five most interesting agency projects involving basic research which are currently in progress are:

- "Enhancing Biological Production of Ammonia from Atmospheric Nitrogen and Soil Nitrate," J. M. Lyons, University of California, Davis. Dr. Raymond C. Valentine, from the University of California at Davis, has been an active investigator in the area of biological nitrogen fixation for many years. During this time, he received funding from NSF via its basic research directorate, Biological and Medical Sciences (BMS), now Biological, Behavioral, and Social Sciences (BBS), to discover new facts and phenomena on the genetics of nitrogen-fixing organisms. A most important contribution was the observation that mutants of bacteria were able to excrete ammonia into the environment. As his research and interests became more problem-oriented, he sought RANN support for his work.

  Specifically, his initial proposal in late 1974 dealt with the anaerobic, free-living, nitrogen-fixing bacteria, *Klebsiella pneumoniae,* and the objective of his research was to construct more efficient ammonia-excreting mutants and to determine the optimum physiological conditions for growth and nitrogen fixation. Dr. Valentine's most recent publication (first announced at the 1977 National Academy of Sciences (NAS) forum on recombinant DNA research) details the specific requirements of these microbes as well as the implications of this research. Recently, Dr. Valentine has also generated a broader program in biological nitrogen fixation with his colleagues at Davis. This is a multicomponent program (the principal investigator is J. M. Lyons), the overall goal of which is to utilize solar energy to enhance the production of ammonia from atmospheric nitrogen or soil nitrate by biological systems. Major objectives are:

  (1) Enhancing the nitrogen-fixing capability of natural bacteria that possess this characteristic by genetically constructing superior mutants

  (2) Increasing the efficiency of symbiotic nitrogen fixation in legumes by identifying naturally occurring and genetically constructed variants of the *Rhizobium* bacteria and the host legume

  (3) Maximizing nitrogen fixation in cereals, especially rice, through the use of the symbiotic fern *Azolla* and blue green algae

  (4) Conserving fixed nitrate nitrogen by genetically modifying typical soil microorganisms and by identifying and controlling

the regulatory steps of nitrate assimilation in plants.

The incentives and payoffs for conducting research on biological nitrogen fixation are rather evident. Crop production is often limited by available nitrogen fertilizer, and green plants normally fulfill their nitrogen requirements by reducing nitrate to ammonia. Only bacteria and blue-green algae are capable of catalyzing the reduction of atmospheric nitrogen gas to ammonia at ambient temperature and pressure. Some plants, however, have evolved symbiotic associations with nitrogen-fixing bacteria or blue-green algae which utilize solar energy captured in photosynthesis to produce ammonia from molecular nitrogen. In order to meet future world food needs, it is crucial to maximize the biological potential for producing ammonia and nitrogen-containing organic compounds from both atmospheric nitrogen and soil nitrate.

- "Production of Hydrogen by Marine Blue-Green Algae," A. Mitsui, University of Miami. Tropical and subtropical marine environments contain many different species of blue-green algae and photosynthetic bacteria that are capable of producing the chemical, hydrogen gas, from renewable resources. Marine blue-green algae are particularly attractive for they are able to produce hydrogen gas from water using sunlight as the ultimate source of energy. Previous support by RANN to the principal investigator, Dr. Mitsui, focused on the collection and isolation of superior hydrogen-producing photosynthetic organisms from marine environments. Under a two-year grant, promising microbes were discovered, and one particular blue-green algae is a very active hydrogen producer for extended periods of time (days instead of the usual minutes). This research follows logically from previous work conducted by Dr. Mitsui and centers on the characterization of the more promising microbes and the enhancement of hydrogen production.

  Specifically, the objectives of this research project are to characterize promising species of marine blue-green algae in terms of relevant biochemical properties and to optimize this biological phenomenon of enhanced hydrogen production by appropriate environmental (physiological) means. Key parameters to be examined for enhancing hydrogen production are: Light intensity, temperature, pH, salinity, and nutrients.

- "Attempted Production of New Agricultural Plants through Protoplast Culture," A. Galston, Yale University. The research project attacks the principal bottleneck in the application of molecular and cellular genetics to practical plant breeding, namely, the development of protoplasts (cells stripped of their rigid cell walls) that are amenable to genetic manipulation, into whole, complete plants.

  Traditional plant breeding practice, based on crossing of mature plants, while eminently successful, is tedious and exceedingly time consuming, often requiring four to five years before a new plant variety is properly characterized. Success in this work will greatly simplify the methodology and reduce the time-span needed to develop a useful new plant variety.

  The results obtained under previous NSF grants suggest that lack of full development is due to rapid aging of the cells, and hence, protoplasts derived therefrom, after the leaf tissue is removed from the plant. In the current grant, emphasis will be placed on means to prevent this aging by appropriate pretreatment of the leaf tissues so as to yield protoplasts with maximum vigor and biosynthetic capacity.
- "Nitrate in Effluents from Irrigated Lands," P. F. Pratt, University of California, Davis. Because crops do not utilize all the nitrate supplied by fertilizers, some nitrate leaches into tile lines, or it drains to underground water bodies. The resulting contamination can cause the eutrophication of surface waters, or it can lead to the accumulation of nitrate in surface or underground drinking water supplies to levels posing a public health hazard. In the irrigated farmlands of the western States, nitrate levels in waters draining below the root zone often substantially exceed the U.S. Public Health Service standard for drinking water. The needs of society for agricultural productivity and for environmental protection come into conflict because of the tendency for a productive agriculture to leak nitrate into water supplies.

  This project is designed to help reconcile these conflicting needs by determining how soil conditions and farm management practices control the leaching of nitrate, and by relating these findings to knowledge of nitrogen requirements for optimum crop production.

Laboratory and field determinations of the rates of transformation of different nitrogen substances in soils under drainage conditions have been completed. Mathematical models are now being developed to describe the downward movement of water and nitrate under irrigation and cropping cycles. During the next two years, the researchers will focus on integrating the results of the entire program into a user-oriented output in the form of interpretations of standard soil mapping associations for characterizing cropping systems as to their tendencies to release nitrate to drainage pathways. This will result in the ability to determine what soil/crop management systems are most likely to contaminate water supplies and how alternative practices can be adjusted to minimize nitrate pollution.

- "N-Nitroso Derivatives of Pesticides," D. Fine, Thermo Electron Corporation. According to the Environmental Protection Agency (EPA), "A family of chemical carcinogens, the nitrosamines, have no equals." Nearly every nitrosamine subjected to animal toxicology studies have been found to be carcinogenic. Many agricultural herbicide, insecticide, and fungicide formulations in use today contain compounds that are secondary or tertiary amines or compounds that can be readily hydrolyzed to form secondary amines. Since it is known that these amine groups do react with nitrite ions to form nitrosamines, it is presumed that these reactions can occur with pesticides and nitrites in soil.

  After a series of discussions with representatives of EPA's Southeast Research Laboratory in Athens, Georgia, a collaborative project was developed involving Thermo Electron Corporation, EPA, the U.S. Department of Agriculture (USDA) to investigate the formation of nitrosamines through the action of soil nitrites on amine-type pesticides.

  With instrumentation developed at Thermo Electron Corporation Dr. Fine and his coworkers were to examine samples of soil, water, and agricultural crops collected by EPA and USDA from areas in the United States that were treated with known amounts and types of pesticides and determine the amounts of nitrosamines, if any, in these samples. Before initiating this phase, laboratory studies of the amine-type pesticides were to be made to assay their chemical content and ability to react with nitrites.

  After examination of the pesticide formulations, unusually high levels of the nitrosamines were found in specific commercial grade herbicide formulations used for household as well as agricultural purposes. These nitrosamine levels were considered well in the range that can be hazardous to man. This unexpected finding of nitrosamines in herbicides as produced by the manufacturer led to a preliminary survey of nitrosamines in other products where the potential also exists. As a result, certain cutting oils used in metal working and machine shops were found to contain over 1,000 parts per million of nitrosamines, a concentration that could only be described as enormous, from a toxicological point of view.

  As a result of these findings, affected industries have begun taking steps to control the problem by repackaging and reformulating products. The National Institute of Occupational Health and Safety (NIOSH) circulated a *Current Intelligence Bulletin* advising industrial concerns on health measures that ought to be taken in the factory environment. In addition, a surveillance and monitoring program, follow-up epidemiological studies, and annual testing studies are also being carried out by NIOSH on the cutting oil problem.

  Because of the importance to public health of the unexpected findings on the project, the Foundation has encouraged the grantee to accelerate the research to an earlier conclusion and to extend it to an examination of a much wider range of products.

The question of research priorities for the next 3 to 10 years is difficult to respond to for two reasons: First, research planning depends to a large degree upon available future resources. Second, RANN program objectives are problem-oriented in nature and usually do not focus on basic research issues, at least in the long term. The passage quoted in the first paragraph of this discussion of the Directorate for Research Applications describes the part played by basic research support in RANN programs. In the long term, it is almost impossible to separate out the basic research priorities from the problem-oriented objectives. With this caveat, there are listed below some of the near-term basic research priorities of programs that currently have a relatively high basic research component:

- To obtain a comprehensive data base on the nature of earthquake motions at typical sites and in representative structures, and to develop new and improved understanding of the dynamic and long-term behavior of structures

with respect to earthquakes and other dynamic hazards

- To devise *in situ* and laboratory methods to determine the dynamic properties of soils and analytic procedures, including the potential for failure of slopes, embankments, and foundations
- To increase the base of knowledge on alternative social adjustments to earthquakes and other dynamic hazards, and to develop an understanding of the factors that influence public utilization of earthquake mitigation methods
- To identify and quantify chemical pollutants in the environment, including but not limited to those associated with known hazards
- To define the exposure of ecosystems and human populations to chemicals by determining chemical pathways and transformations in the environment
- To advance the technology of pollution diagnostics, including new measurement methods for contaminants and screening techniques for detecting adverse biological effects
- To investigate the interface of appropriate biochemical (enzymatic) and chemical systems for converting lignocellulosic materials
- To investigate nitrogen-fixing symbiotic systems (bacteria/plants or algae/plants) for enhancing this biological phenomenon. The focus should be on the interrelationship of nitrogen fixation with the overall biochemical energetics of the organisms
- To investigate the biophotolysis of water to hydrogen gas with biological systems that ultimately derive their energy from the sun.

The following are just a few of the many areas involving basic research not now supported but deserving of support by the Foundation:

- Bio-solar energy conversion. Emphasis should be placed on examining plants and microbes living in adverse or unusual habitats for their adaptability characteristics in order to understand the relevant phenomena and to be able to manipulate these organisms for enhanced net productivity of selective constituents (chemicals, medicinal compounds, solvents, etc.). Also, research should be directed to assessing the potential of biochemical fuel cells, especially enzymatic fuel cells based on the substrate methanol, and photo-biochemical energy converters (solar energy to electricity).
- Global CO_2 problem. As industrialization has occurred on a worldwide basis, more carbon fuels are being burned, greatly increasing the carbon dioxide input into the atmosphere. The carbon cycle, as represented by carbon dioxide emission into the atmosphere and the fixing of carbon by plants, is not adequately understood. The consequences of increased or decreased carbon dioxide in the global atmosphere may substantially affect the climate and, therefore, agriculture productivity. Research initiatives are required to develop an understanding of the sources, sinks, and transformations of carbon as it interacts with the atmosphere and biological materials.
- Constrained economy. The constrained economy program focuses on the problems faced by the United States and the world as a result of the growing number of environmental and other constraints that affect economic growth. In pursuing the study of these problems, it will be necessary to examine basic economic theory to determine if it is adequate for analysis and understanding of the transition from an economy of expansionary and often wasteful growth to one more mindful of the preservation of critical resources, the quality of the environment, and the quality of life. It may be necessary to expand the definition of natural resources to include environmental factors, and to develop new economic tools to deal with production and consumption decisions in relationship to the environment.
- Drought management. Research is needed in order to understand more clearly how people react to and deal with conditions of drought, with particular emphasis placed on the social, behavioral and economic aspects of the actions of individuals, families, institutions, and governmental units.
- Structural design. More fundamental knowledge needs to be gained concerning the structural design process (mechanical, materials, etc.). For example, very little is known about the interaction of people and structures. More basic knowledge is also needed in other areas of design and engineering, e.g., machine design (kinematics and kinetics), human factors research, and industrial engineering.

Organization and Management of Research Activities

The RANN program is regularly coordinated with other Federal agencies at three levels—policy, program, and project. Policy coordination is achieved through the RANN Interagency Coordination Committee, made up of representatives of more than 20 agencies. Program coordination takes

place through interagency panels established under the Coordinating Committee for each RANN subactivity. In addition, special panels and task forces are employed for coordination when required. At the project level, in addition to the review requested of the scientific and State and local community, RANN requests reviews from other agency officials of research proposals that bear on the interests or programs of their agencies.

Although the lead agency concept generally works effectively, it is often beneficial to avoid designating a lead agency in the early stages of research in order that varied approaches to the problem can be explored by different groups. At the time when it appears feasible to focus the effort or to give priority to certain programs (e.g., development of solar energy), it is desirable to designate a lead agency.

DIRECTORATE FOR SCIENTIFIC, TECHNOLOGICAL, AND INTERNATIONAL AFFAIRS

International scientific activities and science information activities both international and domestic are an important part of the National Science Foundation's support of basic research. In these fields, "support" takes several forms—in addition to direct funding of research—over a range encompassing support of United States participation in international scientific bodies, joint projects by American scientists and colleagues overseas, and the improvement of the dissemination of scientific information domestically and internationally. These programs have moved through a series of organizational changes and for a year have been under a single, newly created Directorate for Scientific, Technological, and International Affairs (STIA). Within that Directorate, two main areas are of particular importance to basic research: International programs and science information. Two other areas having a less direct but substantial bearing on research are policy research and analysis, and science resources studies. These serve the Foundation's statutory responsibility to "appraise the impact of research" and "to evaluate the status and needs of the various sciences."

International Cooperative Research

This program has as a principal purpose, in addition to its objectives in behalf of United States foreign policy, the strengthening of American science through access to unique facilities, data, ideas, and expertise abroad. There is a reciprocal benefit for international science through access to the American scientific community by foreign scientists visiting here and those visited abroad.

The array of projects under this program largely mirrors the domestic research priorities of the Foundation, and most have a significant basic research component. The Foundation's role in international scientific cooperation has increased in scope and intensity. At present, there are 21 bilateral agreements; in 16 of these the Foundation has sole management responsibility as the executive agent for the Federal Government; in 5, the activity is carried out by the National Academy of Sciences with Foundation support. Further international activities take place in seven Joint Cooperative Commissions in which the Foundation has a presiding or membership role; through support of United States participation in international scientific bodies; through international travel by individual United States scientists; and through the use of United States-owned excess foreign currency for projects to be performed in the country of its origin. Such projects must involve participation by United States scientists and be of high scientific merit and of benefit to both countries.

Cooperation under formal intergovernmental agreements may take the form of joint research projects, seminars, and visits back and forth to teach or conduct research. These activities take place over a wide range of research fields, including the life, physical, and social sciences, and engineering.

Examples of United States cooperation planned or achieved include: With Japan, seminars on earthquake prediction; with India, work in solid state physics; with Hungary, work on the behavior of molecules during the formation of polymers; with Pakistan, a seminar on genetic control of diversity in plants; with the Soviet Union, joint projects in metallurgy and chemical catalysis; with the People's Republic of China, discussions there, by visiting American scientists, in the fields of insect control, solid state physics, pure and applied mathematics, the Liaoning earthquake, steroid chemistry, and biochemistry. (The Chinese delegation, visiting the United States, was primarily interested in technical subjects.) With Egypt, there have been projects in historical geology and the physical adaptation of large animals to desert conditions; and with Polish scientists, the designing of a novel instrument to measure the contact angle between liquid and solid surfaces more accurately—an assist to basic studies of the surface

energy of liquids, and fundamental to many industrial processes.

Science Information

The Foundation has statutory responsibility under its own charter to foster interchange of scientific information among scientists in the United States and foreign countries and to act to further the full dissemination of information of scientific value. The National Defense Education Act of 1958 established the Science Information Service in the Foundation, requiring that Office to take steps for more effective dissemination and "undertake programs to develop new or improved methods, including mechanized systems, for making scientific information available." Since then, an extraordinary growth of information and extraordinary advances in means of dissemination—notably electronics and computers—have made individual transmissions easier while making the total task of dissemination ever more formidable.

The Division of Science Information of NSF is the only major source of funding in the United States for research in ways to improve science communication across all disciplines and fields. (It is concerned also with technical information, but the focus in this discussion is on scientific information including that on basic research.) Research in the Division is focused in four areas: Information science, user requirements, access improvement, and management and coordination.

Science Resources Studies

The primary objective of this program is the development of factual and analytical information to provide the basis for national planning and policy formulation in the field of scientific and technical resources. Such studies provide, among other things, sharp definition of the basic research sector in terms of the human, financial, and institutional resources available to it. The activities of the Division of Science Resources Studies generate the major portion of U.S. science resource statistics.

Publications of the Division, many of them periodicals, constitute a primary and continuing source of detailed information for the Federal Government and private and public research and development institutions, as well as for the Foundation. A biennial publication, titled *Science Indicators,* designated in the years of issuance as annual reports of the National Science Board, compiles the results of surveys and analysis together within a single cover, offering illuminating text and a wealth of reference material in the form of charts and tables. The data and other analyses and interpretation by the various parts of the Division give insight also into current and long range science and technology policy issues.

DIRECTORATE FOR SCIENCE EDUCATION

Stated informally, the principal aims of the Science Education Directorate are first, to improve the science education system through support of institutions and individuals; and second, to foster science literacy.

Formally, and in more detail, the goals of the Directorate's programs are:

- Science personnel improvement. To identify and encourage scientific talent; to assist in the maintenance of high standards and quality in the training of students and professionals in the sciences; and to stimulate more participation in the sciences by minorities, women, and the handicapped.
- Science education resources improvement. To strengthen and improve the quality of science instruction and research training in schools, colleges, and universities; and to provide incentives for the use of validated knowledge and effective instructional strategies in science education.
- Science education development and research. To advance knowledge of how scientific concepts, processes, and skills are learned; and to encourage the development of means by which the quality, relevance, and efficacy of learning processes in science can be improved.
- Science and society. To bring about greater understanding of science (and technology) as it affects contemporary life including the social and ethical implications of an increasingly technology-dependent society.

The Foundation has a responsibility under its charter to strengthen science education at all levels. The importance of research as part of the process of education in science is recognized by programs of support for research at all levels, ranging from first efforts by young students, which in some cases they themselves originate and carry out, to projects by students at the graduate and postdoctoral level, faculty fellowships, and programs for faculty research participation in industrial laboratories and research institutes.

It is one of the assumptions of the education programs that young people seeking careers in

science will best be served by programs that prepare them for several career options in science and related fields.

Some of the questions driving the science education programs are:

- What constitutes student success in science and how can it be measured? What personal characteristics contribute to individual achievement in science? The results of these efforts should help identify the effects of school science programs, teachers, and nonschool programs on student achievement.
- What are the relationships between the teaching strategies employed and student motivation or student comprehension and retention of scientific information and procedures? This inquiry will provide new insights on the relationship of classroom teaching techniques and processes to student learning and performance.
- What important questions in science education remain unanswered? Work on this question will provide a mechanism for addressing current science education issues by conducting a critical analysis of the existing body of scientific and educational research results.

SMITHSONIAN INSTITUTION

Submitted by David Challinor, Assistant Secretary for Science

Smithsonian Mission

The Smithsonian Institution was created by an Act of Congress in 1846 to carry out the terms of the will of James Smithson of England, who had bequeathed his entire estate to the United States of America "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men."

The Smithsonian of today is both a leading research center and a vast museum complex. The Smithsonian operates eight major research/museum facilities which include the National Museum of Natural History and National Museum of Man, the National Air and Space Museum, National Zoological Park, the Smithsonian Astrophysical Observatory (Cambridge, Massachusetts), Smithsonian Tropical Research Institute (Canal Zone), the Radiation Biology Laboratory (Rockville, Maryland), and the Chesapeake Bay Center for Environmental Studies (Edgewater, Maryland). In addition, the Smithsonian operates a number of units primarily to service the scientific community, the foremost being the Smithsonian Science Information Exchange, Incorporated.

The unique nature of the Smithsonian, with a specific and unambiguous charter for the conduct of basic research, sets it apart from almost all other scholarly organizations in the United States. Unlike universities in this country, the Smithsonian can continue long-term studies that may not otherwise be economically viable. By the same token, the Smithsonian is able to pursue areas of research that mission agencies may find in the short term unprofitable or that may be restricted by their mandate.

Definition of Basic Research

The Smithsonian of late has reexamined the validity and usefulness of the distinction between basic and applied research. In general, these kinds of research are defined in terms of the end product. For basic research, the end product is commonly thought of as investigation for the advancement of scientific knowledge in general. The goal of applied research is usually described as the discovery of new scientific knowledge with a specific objective in mind. This reexamination of the distinction between types of research has led the Smithsonian to think of its scientific pursuits as "original research"—research that provides the baseline data essential for policy planners in mission-oriented agencies.

Role of Basic Research

The Smithsonian of today might be aptly called the Nation's environmental bureau of standards. Our many bureaus have consistently been involved in the assembly and exploration of basic information and measurements about the earth's environment (and the various associated observations emanating from the universe) which affect our biosphere, cultural development, and indeed the way we live. Additionally, our anthropological collections document man's influence on the environment. For more than a century and a quarter, the Smithsonian has been looked to by its scientific colleagues and laymen to maintain, augment, and improve upon one of the major data banks in existence dealing with natural phenomena. The collections of the Smithsonian are central to the scientific process for they provide continuity and a source which a scientist may return to time and time again for information. As technology improves, even more data can be gleaned from one single object.

While all the Smithsonian research bureaus are involved today, those most heavily engaged historically in this census or inventorying process have been the National Museum of Man, with its various collections; the Astrophysical Observatory; and the Radiation Biology Laboratory.

Basic research has always been at the center of the Smithsonian's existence since its founding.

The Smithsonian's development of the national collections did not occur until 1858 when the National Cabinet of Curiosities was transferred from the Patent Office. Some 20 years later, the Congress first passed a bill establishing the "National Museum." The Smithsonian's responsibility to the public is not neglected in pursuit of research, but it has used the solid foundation of facts developed through research to develop its exhibits program.

Throughout the years, the Smithsonian has been among the pioneers of American science. The work of early scientists like John Newberry, who in 1858 navigated the largely unexplored Colorado River, assisted the western expansion of the United States while making an immeasurable contribution to the geological sciences. Robert Kennicott's journey in 1864 from the Yukon River to the Bering Strait provided the first elementary data on what was then Russian America, now Alaska. In 1867, a young ex-Army Major, John Wesley Powell, began his long association with the Smithsonian that developed into the Bureau of American Ethnology, which did more to salvage the languages, legends, and customs of the American Indian than did any other group in the United States.

The Bureau of American Ethnology was not the first research project to be supported by the Government for the Smithsonian. In 1871, Secretary Spencer Baird was asked to head a commission to investigate the disastrous decline of Atlantic food fish. This work developed into the United States Bureau of Fisheries, now called the National Marine Fisheries Service (NMFS), a part of the National Oceanic and Atmospheric Administration of the Department of Commerce.

In aeronautics and astrophysics, the Smithsonian, in 1860, assisted Thaddeus Lowe, whose use of balloons aided the Union effort during the Civil War. In 1896, Secretary Samuel Langley, after working many years on the concept of "mechanical flight," tested his aerodrome and, despite the short distance involved, proved the feasibility of flight via this mode. In 1899, the Smithsonian, on the basis of its reputation in the field, received a request for information from a young bicycle maker named Orville Wright. Concurrent to this activity, Langley also studied how solar radiation might affect the world's weather. The revolutionary nature of this theory is only being recognized today. Langley's interest in this field led to the development in 1895 of the Smithsonian Astrophysical Observatory.

In 1916, the Smithsonian again by fortuitous circumstances began an association with another remarkable scientist, Dr. Robert H. Goddard. Through the assistance of the Smithsonian, Goddard was able to nurture his work, which led to the development of modern rocketry. Along with Goddard, another Smithsonian Secretary, Charles Abbot, continued the work of Langley on solar radiation as a key to weather. Abbot discovered that the variation in the sun's radiation follows a regular pattern of fluctuation. Work in this area continues today through the Langley-Abbot program at the Astrophysical Observatory and the long-term monitoring of radiative sources by the Radiation Biology Laboratory.

Examples of Basic Research

Among the many current research projects undertaken by the research bureaus of the Smithsonian, a number of projects stand out as leading toward the solution of contemporary problems and expanding the frontiers of known scientific knowledge. Our scientists have recently discovered two archeological sites in northeastern Colorado which indicate that man has been in the New World nearly 20,000 years earlier than the previously accepted dates of 11,500 B.P. Working near Wray, Colorado, this expedition unearthed the most complete Pleistocene record yet discovered of man's cultural history in the Americas. The localities, known as the Dutton and Selby sites, contain evidence that ice age hunters killed and butchered extinct megafauna such as a mammoth, ground sloth, peccary, giant bison, camel, horse, as well as deer and antelope. These ancient hunters, with known antecedents in Siberia using only bone tools, appear to be considerably more sophisticated than previously supposed. These finds will call for an entire reevaluation of archaeological theory for the New World.

Scientists at the National Museum of Natural History have been using amphipods in crucial monitoring programs to guard against marine pollution in projected tanker ports and other coastal regions. By understanding the physiological tolerance of amphipods to oil pollution, scientists are able to determine at just what level pollution will tip the balance adversely to disrupt the entire marine ecosystem. Smithsonian scientists are able to provide the "purity of culture" to these monitoring programs by assuring proper identification of specimens. Quite often, we have found environmental managers using erroneous specimens in developing antipollution plans. By utilizing our standardized collections, managers are able to develop antipollution plans based on correct tolerance levels, hence avoiding countless errors and wasted dollars.

At the Chesapeake Bay Center for Environmental Studies, scientists over the past three years have been undertaking basic research on the effect of land run-off on estuarine water quality. In this

study, some nine square miles of land area have been monitored to determine the quantities of nutrients, sediments, bacteria, and pesticides entering an estuary from its watershed. This research has now enabled investigators at the Center to predict the effects of future changes in land use over a large geographical area on water quality. As a result, other Federal and State agencies are using this information in their own land use and water quality management programs.

The Radiation Biology Laboratory has been monitoring ultraviolet radiation (UV) for a number of years at stations throughtout the world. Several sites were chosen for their relatively undisturbed nature, hence less damage to the environment from UV is noticed. The continual monitoring activities will allow our scientists to inform responsible managers of any variance in the UV, and it is hoped that this will allow adequate time by officials to take whatever necessary actions are needed to halt potential harmful effects on the environment.

At our Tropical Research Institute in Panama, scientists are studying forest regeneration and growth. In the tropics, the problems of replacing a forest after its destruction are much different from allowing a New England farm to lay fallow. Scientists are concentrating on natural gaps caused by tree falls or storms on our reserve on Barro Colorado Island, larger gaps caused by farming on the mainland, and an enormous area in a virgin forest near the Colombia-Panama border which was denuded by earthquake-induced landslides last fall. The results of these studies of different area forest gaps will help us understand how to conserve and restore tropical forests, an ecosystem that may have an important relationship to the water balance and weather beyond the limits of the Tropics of Cancer and Capricorn.

Smithsonian scholars are also engaged in studies of natural habitats critical in the preservation of endangered species, the preservation of economically important waterways in the United States, and development of alternate food sources and sources of energy. Moreover, at the National Zoological Park's Research and Conservation Center at Front Royal, Virginia, research into the breeding activity of endangered species is being carried out. This research will ultimately lead to better management of captive animals and provide greater knowledge in the fields of animal behavior and reproduction.

Organization and Management of Research Activities

Research at the Smithsonian is generally screened at several levels concerning its utility, productivity, and duration. This is accomplished by review at the department or division level, the Director's level, by the Assistant Secretary, and in some instances by the Secretary. The Secretary of the Institution is charged with the overall policy direction of the research with the Assistant Secretary for Science as his principal adviser. By and large, scientists are autonomous in the pursuit of their research within the overall goals of each research unit. The bureaus of the Smithsonian are periodically subject to peer review by Visiting Committees and through mechanisms such as the Smithsonian's research awards program. The latter program finances new or continuing research projects formerly eligible for support from the National Science Foundation (NSF). The program maintains a distinguished outside advisory committee which reviews the work of applicants.

Certainly the prohibition of seeking funds from the NSF has impinged greatly on the ability of the Smithsonian to support its programs. Except for strictly defined instances, the Smithsonian cannot seek funds from the NSF and must find its outside support from other organizations. Success with foundations and other private organizations is critical in order to undertake new enterprises outside the traditional interests of the Institution. Quite often, we have found these new enterprises to be discouraged by the Congress, which requires going outside for assistance. Foundations, on the other hand, have been reluctant to support the types of projects proposed by the Smithsonian, since it is felt that these areas are the responsibility of the Congress. In addition, trends within foundations of late have favored the applied approach or criteria which fit into the distinct mission or traditional interest of the particular foundation. This is an ominous sign since philanthropic organizations have always been the lifeblood of change in recent years as the Government's policy has moved toward retrenchment.

Additional difficulties are faced by the Smithsonian in meeting the goals and objectives of the Federal personnel system. Hiring procedures and salary limits quite often impede the progress of research and result in the loss of top-level job candidates to private industry and academia. Added inducements are necessary to acquire or retain quality scientists.

Another critical area which is in need of extensive study is how the research community can best relate its work to laymen. This is an era of great skepticism in which motives are highly suspect and traditional values are held up to ridicule. In part, the Smithsonian has met this challenge through its exhibits program, by an easy translation of research results into highly educational and oftentimes entertaining presentations. Much more is

needed, however, if the research community in this time of economic conservation is to keep pace with its counterparts in other nations. More importantly, it must sound the trumpet to this Nation that it might be underinvesting in basic research to the detriment of the Nation's future.

Another area of concern should be the care with which we approach areas of research to avoid duplication of effort or overlap. The Smithsonian has taken great pains throughout its history to avoid entering areas where mission agencies were charged in carrying out work. It has, in fact, "spun off" activities in the past (when they have become large enough to survive on their own or were better suited for mission-oriented agencies). Among the activities derived from the Smithsonian are the National Weather Service, Bureau of Commercial Fisheries (now NMFS), and certain components of NASA.

Much of the Smithsonian's success over the past years can be attributed to its policy to make its information available to all who request it and not to conduct any classified research. The latter has permitted the Smithsonian to work in any country throughout the world whether the United States recognizes that country or not and to work simultaneously in countries such as Israel and Egypt. Such flexibility is the hallmark of the Smithsonian and its passport to the world. A common bond, based on science and not politics, is quickly formed to the benefit of both countries involved.

The Smithsonian will continue to accept the challenges of the future while maintaining its long tradition of expertise and research flexibility. As in the past, the Institution will continue to take great care to eliminate influences that may tend to distort observations or produce faulty results in research. The Smithsonian will continue to recognize that there is not a need to invent problems for investigation, for there are many urgent and practical problems to be met in conjunction with the environment in which we live. Our efforts will continue to be supportive of other research institutions and will be, in many instances, complementary to the general needs of the national and international scholarly community.

VETERANS ADMINISTRATION

Submitted by Dr. John D. Chase, Chief Medical Director

Mission of the VA

The Veterans Benefits law (Title 38 of the United States Code) defines the mission of the Veterans Administration (VA) as "the administration of laws relating to the relief and other benefits provided by law for veterans, their dependents, and their beneficiaries" (38 U.S.C. 201). Among these benefits is a "complete medical and hospital service . . . for the medical care and treatment of veterans" (38 U.S.C. 4101(a)). The law further extends this function by providing that, "In order to carry out more effectively the primary function and in order to contribute to the nation's knowledge about disease and disability, the Administration (of Veterans Affairs) shall, in connection with the provision of medical care and treatment to veterans, carry out a program of medical research . . . ." (38 U.S.C. 4101(c) (1)).

Stated in other terms, the mission of medical research in the VA is the improvement of health care, especially of veteran patients, through scientific efforts. A part of this mission is to provide a better understanding of the biological, chemical, physical, and behavioral phenomena underlying disease, disability, and health through a broad program of investigation of life processes.

Definition of Basic Research

The VA considers as "basic" only research that involves the testing of fundamental life science concepts by the scientific methods. It tends to emphasize molecular, subcellular, and cellular structures and phenomena using methods derived from disciplines such as biochemistry and physics. The distinction between basic and applied research is vague and subject to interpretation; the VA tends to consider as "basic" only those investigations for which no practical application is immediately evident at the outset.

Role of Basic Research

Research in the VA is chiefly "applied" in nature but most advances in the understanding of how to prevent and treat disease result from the findings of basic research. Clinical observations and investigations in turn raise questions that stimulate further basic biomedical research. VA research is almost exclusively intramural, conducted within the system's hospitals by members of its staff who are usually clinicians caring for patients. Under these circumstances, basic research commonly arises from clinical problems and is directed toward a better understanding of the fundamentals of disease processes.

Investigators within the VA include those with advanced training in disciplines such as biochemistry, physiology, genetics, molecular biology, and microbiology. Scientists may be recruited to provide research support for clinical staff members but many are principal investigators of their own projects; some are physicians with special scientific training. Since the VA's research program supports investigator-initiated research, most basic research is proposed and pursued by this specialized group.

The VA supports and indeed encourages basic research within this framework. It does not and cannot undertake basic research on the broad or intensive scale characteristic of special institutes, nor can it support extramural programs in fundamental sciences.

Examples of Basic Research

Following are examples of basic science research in the VA:

Roger H. Unger, M.D., control of carbohydrate and fat metabolism by pancreatic hormones, especially glucagon.

Andrew V. Schally, Ph.D., physiology and biochemistry of hypothalamic neurohormones, especially thyrotropin releasing hormone and luteinizing-hormone-releasing hormone.

William Oldendorf, M.D., discovery of the principle of computerized axial tomography (CAT).

Robert O. Becker, M.D., electrical control of mammalian tissue regeneration.

Thomas P. Singer, Ph.D., biological energy generation and mitochondrial biogenesis.

Paul A. Srere, Ph.D., citrate metabolism and cellular adhesion.

John W. Porter, Ph.D., lipid synthesis.

Robert Efron, M.D., temporal aspects of auditory perception.

Rosalyn S. Yallow, Ph.D. and Solomon A. Berson, M.D. (dec.), development of radioimmunoassay.

Current and Future Research Emphasis

The VA will continue to support intramural basic biomedical research. It currently is especially interested in dedifferentiation and redifferentiation of neural tissue, the biochemical and structural changes of aging, and the metabolic basis of alcoholism. There is no intention to broaden the scope of the basic research beyond the present relatively narrow, mandated limits.

Organization and Management of Scientific Activities

Management Structure

Research in the VA is largely decentralized, as well as intramural and investigator-initiated. There is, therefore, a research organization within each participating VA health care facility in addition to a research and development office in the VA Central Office.

The usual hospital organization includes an Associate Chief of Staff for Research and Development (ACOS) charged with administering the local program. A Research and Development (R&D) Committee, composed chiefly of health care facility staff members, acts as a reviewing, evaluating, and executive body. It usually includes faculty members of an affiliated medical school and uses outside consultants for scientific evaluation. A Human Studies Subcommittee and an Animal Studies Subcommittee review all research proposals for work in their respective areas; other subcommittees are created as needed.

The Office of the Assistant Chief Medical Director for Research and Development in the VA Central Office contains three Services: the Medical Research Service, the Rehabilitative Engineering Research and Development Service, and Health Services Research and Development Service. Basic science is almost exclusively under the aegis of the Medical Research Service.

This Service uses three mechanisms to assess basic research proposals and the progress made under them: Evaluation by an appropriate expert from within or outside the VA; review by a Research Advisory Group; and evaluation by a Merit Review Board.

There are four Research Advisory Groups, each with three VA professional staff members, an ACOS, an investigator, and a clinician. Each Group considers applications for one-time research funding from a health care facility located in a part of the country from which its members are not drawn. In order to provide specialized evaluation, the Medical Research Service arranges for review of each application by a VA scientist who is expert in the relevant research field before the Group considers it.

Each Merit Review Board, in contrast, deals with one area of medicine or science and the preponderance of its members comes from outside the VA. The members are chosen for their scientific expertise and research experience so that additional technical opinions are needed only occasionally.

The senior staff of the Medical Research Service acts as an administrative reviewing body for the programs evaluated by the Regional Advisory Groups and the Merit Review Boards. This allows separate consideration of scientific merit and of relevance to the VA's mission.

Initiation and Review of Basic Research Projects

Basic research projects are proposed by VA investigators themselves, then are developed and presented in writing by them to the R&D Committee of the investigator's hospital. Any proposal to use animal subjects must be approved as reasonable and ethical by the Animal Research Subcommittee; any involving human subjects must satisfy the Human Studies Subcommittee that the integrity and rights of the subject are protected. The R&D Committee can obtain evaluation of the proposal by an expert before deciding whether to support it.

Large programs must be submitted through the VA Central Office's Medical Research Service to Merit Review Boards after R&D Committee approval. The Board recommends on scientific grounds that the program should be approved or disapproved and if approved, assigns it a priority rating as well as commenting on its funding. Generally, approvals are for four years or less at which time the Merit Review Board evaluates the progress and proposed future course of the research.

In these decisions the Board serves as an evaluator for the R&D Committee of the local facility and for the Medical Research Service, the latter during determination of the funding allocated to the local facility.

The R&D Committee and the ACOS exercise considerable discretion in the use of the funds provided them. They are also responsible for the continuing evaluation of research in the facility and can implement needed modifications or can terminate an unsatisfactory project.

Peer review of the progress of smaller programs of the individual investigators is arranged by the Medical Research Service to provide scientific evaluation and funding guidance. The health care facility, on the other hand, solicits supplemental funds for unrepeated expenditures by submitting through the Service a comparatively brief request to a Regional Advisory Group. Such funds characteristically support a new investigator until he can submit a formal proposal for peer review but may replace damaged equipment or provide for unexpectedly rapid expansion of a promising project.

The senior staff of the Medical Research Service formally reviews the scientific evaluations by the Regional Advisory Groups and by the Merit Review Boards. It then determines the relevance of each project and its investigator to the VA's mission and research programs in order to arrive at the level of funding allowed for the research.

Direction and Protection of Basic Research Projects

The VA establishes a few areas of medicine for special research emphasis and publicizes these areas among the staffs of health care facilities. In a few instances, centers are created within one or a few facilities to combine patient care with research in a special clinical field, e.g., spinal cord injury. These measures elicit basic research projects as well as more applied ones.

Some R&D committees have diverted funds from basic to applied projects which are more directly in line with the VA's mission. Scientists usually appeal such decisions to the Central Office which can continue support for the basic research projects if they are considered important and productive. The Medical Research Service conducts cooperative clinical studies of a developmental character as the sole major program which could threaten directly the funding of basic research. So far it has not been allowed to do so.

PART II

SELECTED ASPECTS OF FEDERAL SUPPORT OF BASIC RESEARCH

PART II
INTRODUCTION

The agency submissions contained in Part I illustrate great diversity in the financing, management, and conduct of basic research and its relation to Federal missions. There are, however, some cross-cutting trends and problems. This part of the report is designed to provide an overview of these trends and problems as they affect agency research operations, federally funded basic research performers, and the various fields of science (for more detail on the contents of Part II, see the last three subheadings of this introduction beginning with "Problems in the Conduct of Basic Research"). In order to supplement the material in Part I, Part II also draws upon the responses to questions and issues provided to the Board by the agencies (see description of methodology in Appendix C). It also utilizes statistical information on Government- and nongovernment-supported R&D regularly collected by the National Science Foundation.[1] While the primary purpose of this report is not quantitative analysis, selected Government-wide and national data are presented in order to give perspective to the agency comments on the support and conduct of basic research.

Trends in Federal Support

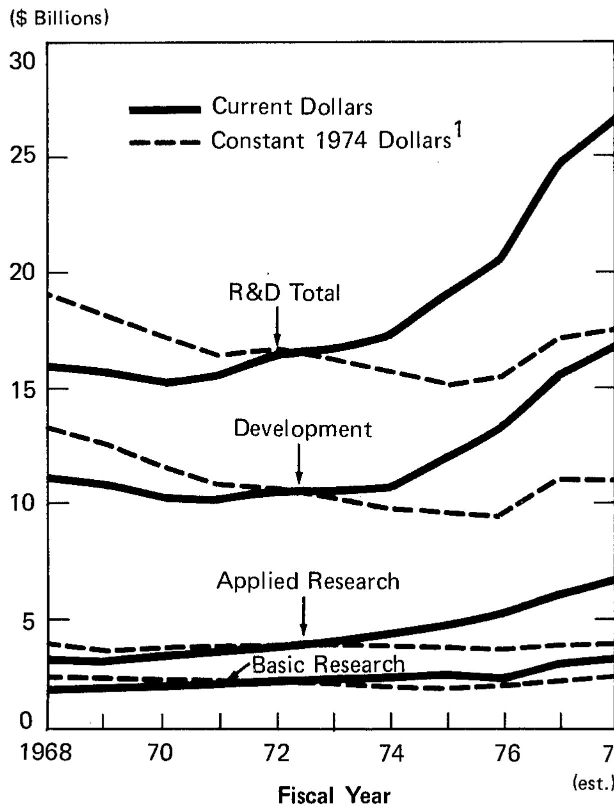
The data on Federal obligations and expenditures for basic research are subject to substantial limitations (described in the Overview section of this report). Nevertheless, they provide a sufficiently reliable basis for analyzing the comparative roles played by agencies and research performers and how the various fields of science have fared. They also help put into perspective the trends in funding levels over the years. The Board has not attempted in this report to analyze the causes for or correlations in funding trends, but offers the latest information available to it for the use of those concerned with basic research funding decisions.

[1]To the extent possible, use is made in Part II of the statistical tables and analyses in *Federal Funds for Research, Development, and Other Scientific Activities* (hereinafter referred to as *Federal Funds*). The primary focus is on data for Federal obligations through FY 1977 (as estimated at the time of preparation of this report). For comparison purposes, estimates are included for FY 1978, along with the President's budget request for FY 1979 (Appendix K). In some cases, particularly for certain aspects of industrial basic research activities (Chapter 2), expenditure data for FY 1975 are used because they are the latest available from industry.

Total R&D Obligations and Basic Research

The trends in federally supported basic research generally follow those of total R&D obligations. Thus, basic research funding, obligations, and budget proposals, in current dollars, have enjoyed a fairly constant growth over the 1968-1977 period, during which total Federal R&D obligations in current dollars increased from $15,921 million to an estimated $24,465 million, or 54 percent (see Figure 1 and Table 1). During this same period, basic research grew 60 percent, rising from $1,721 million to $2,755 million. Basic research enjoyed an average annual growth rate in Federal support of 4.3 percent from 1968 to 1976, but in constant (1972) dollars decreased by 1.8 percent annually. Current-dollar growth rate escalated sharply in 1977 (13.6 percent), and the President's 1978

Figure 1—Federal R&D obligations, by character of work, FY 1968-78



[1]Based on GNP implicit price deflator with estimates for fiscal years 1977 and 1978.

SOURCE: Division of Science Resources Studies/STIA/National Science Foundation.

Table 1.—Federal R&D obligations, by character of work, FY 1968-78

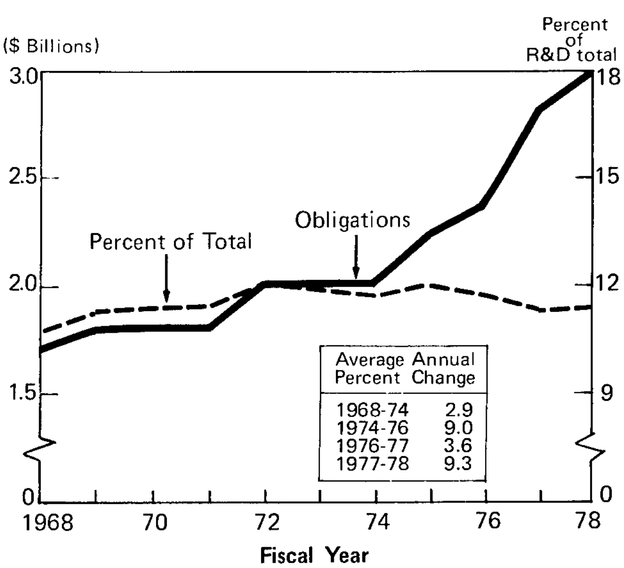
[Dollars in millions]

	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977 (est.)	1978 (est.)
					Current dollars						
R&D total	$15,921	$15,641	$15,340	$15,545	$16,498	$16,800	$17,415	$19,013	$20,759	$24,465	$26,317
Basic research	1,721	1,779	1,762	1,779	1,974	2,001	2,039	2,279	2,425	2,755	3,012
Applied research ..	3,140	2,956	3,455	3,720	3,867	3,914	4,472	4,798	5,448	6,099	6,479
Development	11,060	10,906	10,123	10,045	10,657	10,885	10,904	11,936	12,885	15,612	16,826
					Constant (1972) dollars[1]						
R&D total	19,346	18,145	16,876	16,261	16,498	16,092	15,480	15,260	15,561	17,438	17,698
Basic research	2,091	2,064	1,938	1,861	1,974	1,917	1,812	1,829	1,818	1,963	2,025
Applied research ..	3,815	3,430	3,801	3,892	3,867	3,749	3,975	3,851	4,084	4,347	4,357
Development	13,439	12,652	11,136	10,508	10,657	10,426	9,693	9,580	9,659	11,128	11,316

[1] Based on GNP implicit deflator with estimates for fiscal years 1977 and 1978.

Source: Division of Science Resources Studies/STIA/NSF

Figure 2—Trends in Federal basic research obligations



SOURCE: Division of Science Resources Studies/STIA/National Science Foundation.

budget request ($3,012 million for basic research) represented a further 9.3 percent gain.

Despite this encouraging trend in funding since 1976, basic research obligations for 1978—at the level proposed by the President—still would be 5 percent lower than they were in 1968 in constant (1972) dollars. In relation to other types of research, the basic research share of Federal R&D obligations has remained fairly constant (Figure 2), ranging between 11 and 12 percent (the shares for 1977 and 1978 are both estimated to be 11 percent).

Agency Trends

Seven agencies provided more than 96 percent of Federal basic research funds in FY 1977. They are: the Departments of Agriculture (DOA), Defense (DOD), Health, Education and Welfare (HEW), and Interior, the Energy Research and Development Administration (ERDA) (now the Department of Energy), the National Aeronautics and Space Administration (NASA), and the National Science Foundation (NSF).

Their respective shares of basic research obligations in FY 1968 and FY 1977 are as follows:

Agency	Percent (rounded) FY 1968	FY 1977
HEW	23	27
NSF	15	22
ERDA	16	14
NASA	19	12
DOD	15	10
DOA	5	7
Interior	2	5

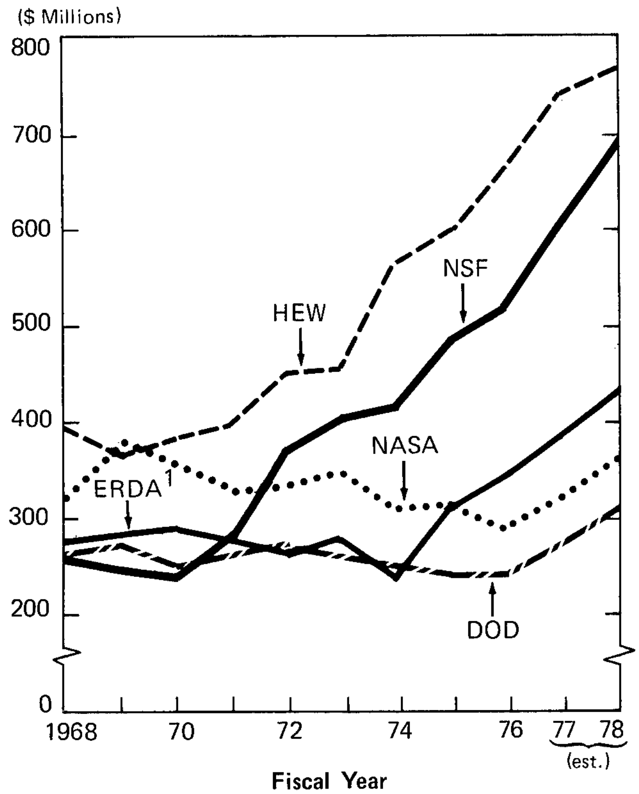
Source: Table 2 and *Federal Funds*, Vol. XXVI (NSF-77-317).

Trends from 1968-1978 for the five leading agencies are shown in Table 2 and Figure 3.

Trends by Performer

The trends in allocation of Federal obligations for basic research by class of performer are shown in Tables 3 and 4 and Figure 4. Universities and colleges have consistently been the largest performing sector and have shown the fastest growth rate in the 1968-1976 period. Since 1976, however, industry and "other nonprofit institutions" and Federally Funded Research and Development Centers (FFRDC's) have outpaced the growth rate of obligations to universities and colleges. The academic sector remained dominant however in FY 1977, as shown by the following relative shares of FY 1968 and FY 1977 obliga-

Figure 3—Federal obligations for basic research, by selected agency, FY 1968-78



[1]Prior to 1974 AEC data were used.

SOURCE: Division of Science Resources Studies/STIA/National Science Foundation.

Table 2.—Federal obligations for basic research by agency, FY 1968-78

[Dollars in millions]

Fiscal Year	*Total*	*HEW*	*NSF*	*ERDA*[1]	*NASA*	*DOD*	*All other*
1968	$1,721	$397	$252	$282	$321	$263	$206
1969	1,779	371	248	285	380	276	219
1970	1,762	388	245	287	358	247	237
1971	1,779	397	273	277	327	262	243
1972	1,974	461	368	268	332	270	275
1973	2,001	458	392	275	350	258	268
1974	2,039	561	415	232	306	244	281
1975	2,279	592	486	313	309	236	343
1976	2,425	652	524	346	293	248	362
1977 (est)...........	2,755	747	606	391	320	275	416
1978 (est)...........	3,012	773	677	429	365	314	454

[1] Prior to 1974 AEC data were used.

Source: Division of Science Resources Studies/STIA/NSF

tions enjoyed by the four major performers of basic research:

	(Percent of total, rounded) FY 1968	FY 1977
Universities and colleges	43	47
Federal intramural	24	29
FFRDC's administered by universities	13	11
Industrial firms[1]	13	7

[1]Includes FFRDC's administered by industry

Trends by Field of Science

The trends in Federal obligations for basic research by field of science are shown in Table 4.3 and Figure 4.1 in Chapter 4. The dominance of the life sciences in the period FY 1968-1977 has been constant, and they have enjoyed a growth over the period (73.9 percent) second only to the environmental sciences (98 percent). The relative shares of Federal obligations for basic re-

Table 3.—Federal obligations for basic research, by major performer, FY 1968-78

[Dollars in millions]

	1968	*1969*	*1970*	*1971*	*1972*	*1973*	*1974*	*1975*	*1976*	*1977 (est.)*	*1978 (est.)*
Current dollars											
Total	$1,721	$1,779	$1,762	$1,779	$1,974	$2,001	$2,039	$2,279	$2,425	$2,755	$3,012
Universities and colleges	745	740	690	777	901	909	963	1,065	1,137	1,290	1,399
Federal intramural . .	410	516	541	491	538	537	611	682	719	791	851
Industrial firms[1]	217	211	205	182	166	213	131	138	152	201	250
Constant (1972) dollars[2]											
Total	2,091	2,064	1,938	1,861	1,974	1,917	1,812	1,829	1,818	1,963	2,025
Universities and colleges	905	858	759	813	901	871	856	855	852	920	941
Federal intramural . .	499	598	595	514	538	515	543	548	539	564	573
Industrial firms[1]	264	244	225	190	166	204	117	110	114	143	168

[1] Includes Federally Funded Research and Development Centers (FFRDC's).
[2] Based on GNP implicit price deflator with an estimate for fiscal year 1977.

Source: Division of Science Resources Studies/STIA/NSF

Table 4.—Federal obligations for basic research, by performer

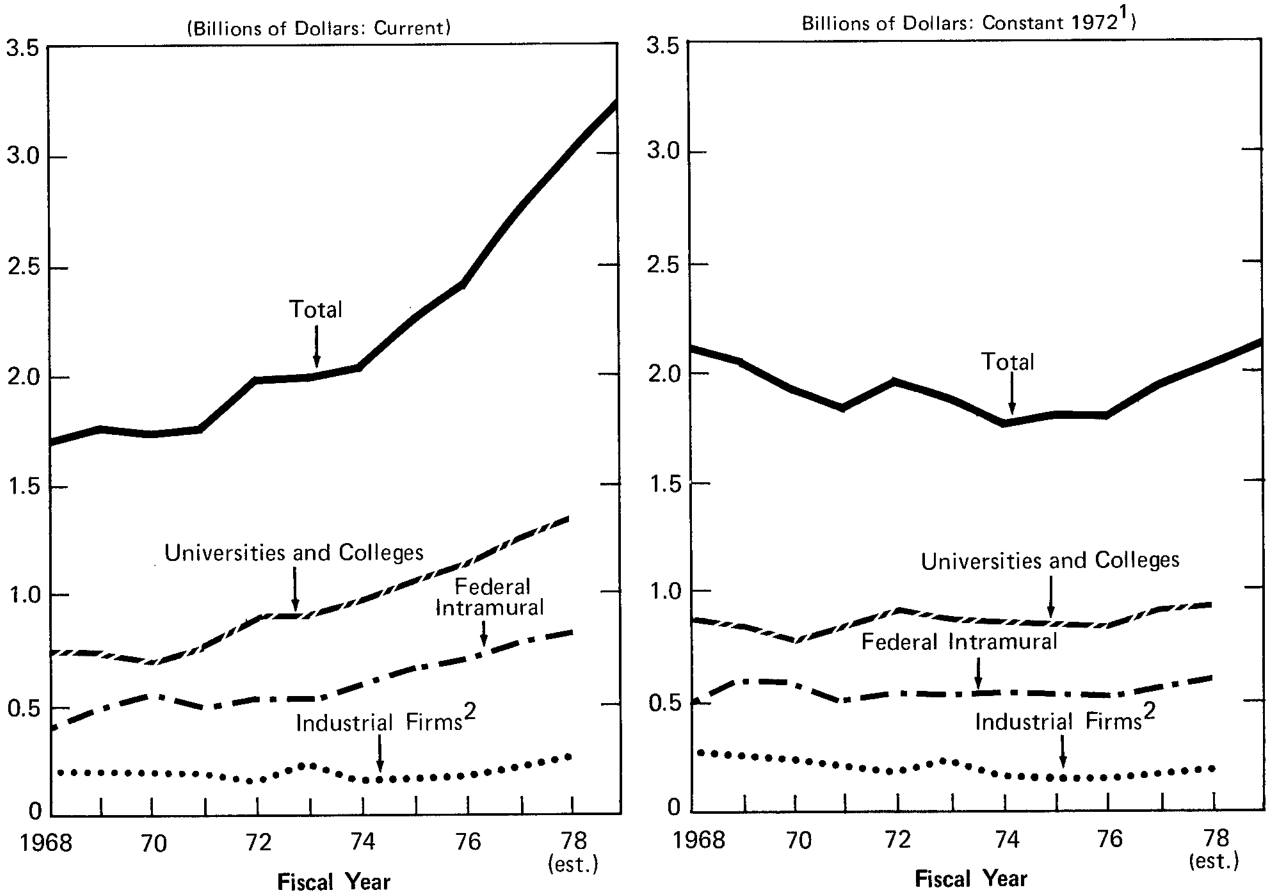
[Dollars in millions]

Performer	Actual 1968	Actual 1976	Actual: Average annual percent change 1968-1976	Estimates 1977	Estimates: Average annual percent change 1976-1977	Estimates 1978	Estimates: Average annual percent change 1977-1978
Total	$1,721	$2,425	+4.4	$2,755	+13.6	$3,012	+9.3
Federal intramural	410	719	+7.3	791	+10.0	851	+7.6
Industrial firms[1]	217	152	−4.4	201	+32.2	250	+24.4
Universities and colleges........	745	1,137	+5.4	1,290	+13.5	1,399	+8.4
FFRDC's administered by universities	225	284	+3.0	315	+10.9	347	+10.2
Other nonprofit institutions[1]	97	108	+1.4	125	+15.7	131	+4.8
Other performers	27	25	−1.0	33	+32.0	34	+3.0

[1] Includes Federally Funded Research and Development Centers (FFRDC's) administered by this sector.

Source: Division of Science Resources Studies/STIA/NSF

Figure 4—Federal obligations for basic research, by major performer, FY 1968-78



[1]Based on GNP implicit price deflator with an estimate for fiscal years 1977 and 1978.

[2]Includes Federally Funded Research and Development Centers (FFRDC's) administered by this sector.

SOURCE: Division of Science Resources Studies/STIA/National Science Foundation.

search at the beginning and end of the period for the leading fields of science are:

	(Percent of total, rounded)	
	FY 1968	FY 1977
Life sciences	34	37
Physical sciences	35	29
Environmental sciences	12	14
Engineering	9	10
Social sciences	4	4
Mathematics and computer sciences	4	3

For further analysis of basic research fiscal detail, see Chapters 1-4.

Problems in the Conduct of Basic Research

The chief concerns of the agencies in the conduct of the basic research they support include sharp annual fluctuations in budget authority and expansion of their legislative responsibilities without commensurate increases in funding. Other concerns have been noted in the Overview and the individual agency submissions contained in Part I as well as in agency responses to the supplementary questions and issues listed in Appendix C. These other concerns vary considerably from agency to agency, but those expressed most often are presented in Chapters 5 to 7. Chapter 5

explains how the agencies decide which research programs and projects to fund and how they conduct intramural research. Chapter 6 presents the problems caused by both general and specific legislation affecting the support and conduct of research. Chapter 7 deals in part with funding problems but emphasizes organizational barriers such as internal budget and personnel procedures and the interpretation of legislative restrictions such as the Mansfield amendment.

Coordination of Basic Research

While there are obvious problems in coordinating basic research in support of individual agency missions (including definition of the term), the extent of joint funding, management, consultation, and other activities designed to achieve this goal is surprising. Chapter 8 is devoted entirely to this subject; it traces the coordination process historically and provides an overview of current interagency mechanisms, such as the "lead agency" concept, for achieving greater coordination of the Federal research effort.

Priorities and Gaps

Despite the impressive record of accomplishments and the large and diverse current research agenda, the agencies clearly indicate that there is continuing need for advancement of basic knowledge in order to perform their missions. In many cases, their current research programs address most or all of the priority and gap areas. Chapter 9 deals primarily with how each agency views its needs for more knowledge and how it is hoped that the research underway or projected will fill these needs.

CHAPTER 1

BASIC RESEARCH IN AGENCY LABORATORIES AND FEDERALLY FUNDED RESEARCH AND DEVELOPMENT CENTERS

This chapter focuses on intramural basic research as reported by each agency. It should be emphasized that there is some lack of consistency in the figures for basic research funding. This is illustrated by the difference between the Energy Research and Development Administration (ERDA), which does not include any departmental overhead in the figures it reports, and the National Science Foundation (NSF), for which the reported intramural figure is 100 percent overhead. In general, 10 to 12 percent of the total basic research obligations, representing the administrative costs of running the program, is added to the obligations for basic research actually performed in-house to arrive at the intramural figure; in some cases the administrative costs are considerably higher.

Federal laboratories and the agencies themselves accounted for $791 million (current dollars) of Federal basic research obligations in FY 1977 (see Table 3 and Figure 4 in Introduction). This is the second largest performing sector next to universities and colleges and their share of the total Federal basic research effort has increased from 24 percent in 1968 to 29 percent in 1977. As measured in constant (1972) dollars, total in-house basic research obligations have grown in the 1968-77 decade from $499 million to $564 million, or 13 percent. Over the 1968-1976 period, Federal intramural obligations (in current dollars) rose an average of 7.3 percent annually, registered a 10 percent gain in 1977, and are projected to rise another 7.6 percent in the 1978 budget.

Inasmuch as the scope of this report did not include any assessment of the quality of such research and as there was little opportunity to communicate directly with the laboratories, attention has been focused on (1) the degree of centralized versus delegated program decision making and (2) other interactions between headquarters and the laboratories, including the manner of selecting the laboratory directors. Grade levels of directors and other senior scientists can be important in that they affect the quality of the individuals who can be recruited; such levels vary considerably from agency to agency, but an analysis of this without examining grade structures throughout the agency could give a distorted picture, and thus was not attempted.

There is wide variation in agency use and operation of laboratories. They may be manned by Government employees, contractor employees, employees of a collaboratng organization, or some combination of these. They may have essentially complete autonomy, almost none, or some degree between these extremes. In NSF publications, contractor-operated facilities are categorized as Federally Funded Research and Development Centers (FFRDC's) if:

(1) The primary activity is research and/or development, or the management of R&D;
(2) The work is performed at the request of or under a broad charter from the Federal Government, which also monitors the work;
(3) The facility is a separate operational unit or corporation;
(4) At least 70 percent of the operation is federally funded;
(5) The facility has at least 5 years expected lifetime under contract;
(6) Most or all of the facility is paid for by the Federal Government; and
(7) The facility has an average annual budget of at least $500,000.[1]

It has been the practice for statistical purposes to treat the FFRDC's more or less as though they were part of the contractor's operation, and in a few cases this may be appropriate. In general, however, an FFRDC is much more like an in-house activity of the sponsoring agency, simply being operated for it by the contractor—except that some FFRDC's provide greater flexibility for the use of Government facilities by outsiders.

Department of Agriculture

The Department of Agriculture collaborates extensively with State and local governments and with colleges and universities, especially the land-grant institutions of 1862 and 1890, Tuskegee Institute, and institutions with schools of forestry. These collaborations can result in Government and university scientists working together in facilities that may be owned by the Federal Government or by a university. The university scientists may be supported by Agriculture, but, if so, it is probably with Hatch Act funds at a State Agricul-

[1] *Federal Funds for Research, Development, and Other Scientific Activities*, Vol. XXV (NSF 76-315), p. 55. Hereinafter referred to as *Federal Funds* with appropriate NSF publication numbers.

tural Experiment Station (SAES) or with McIntire-Stennis funds at a State Forestry Research Organization (SFRO).

Agriculture estimates obligations of $194 million for basic research in 1977, 70 percent of which is reported as intramural.[2] This percentage reflects the efforts of Agriculture employees, wherever located. The largest component of this basic research is the $115.9 million of the Agricultural Research Service (ARS), whose work is 94.5 percent intramural, the balance being performed mostly in foreign countries. The intramural work is performed at seven large research centers as well as at many other locations. Two of the research centers are for work on animal disease, four are large regional centers for research on utilization and handling of agricultural products, and one is the internationally recognized Beltsville Agricultural Research Center. Each facility, except Beltsville, is managed by the appropriate regional director, of whom there are four who report to the Administrator in Washington. The Administrator himself handles the Beltsville facility, where he has about half his staff. The other half is with him at headquarters and includes scientists in each major scientific discipline. At each level, laboratory directors are appointed by the next higher echelon with the assistance of a peer review panel. Programmatic decisionmaking is vested with the laboratories but is subject to review by the 67 science-oriented coordinators of the corresponding subject matter National Research Programs (NRP's). The coordinators also make recommendations for program emphasis or reorientation.

The second largest sponsor of basic research in Agriculture is the Cooperative State Research Service (CSRS), which uses the SAES's and the SFRO's and consequently reports a figure of only 4 percent intramural—this presumably being the management cost. The Forest Service (FS) is next with $24.8 million, of which 81 percent is intramural. Again, this figure represents Agriculture employee scientist-years regardless of where the work is performed. Schools of forestry comprise two-thirds of the locations where the scientists work, but there are also eight regional forestry experiment stations, the Forest Products Laboratory in Madison, Wis., and the Institute of Tropical Forestry in Puerto Rico. The directors of these laboratories are appointed by the Chief of the Forest Service. They prepare the budgets that determine their programs and submit these to Washington for approval. Headquarters may change the submission. Each director has the discretion to make shifts of up to 5 percent within the approved budget.[3]

Department of Commerce

The Department of Commerce classifies 77 percent of its $25 million 1977 basic research program as intramural.

The National Oceanic and Atmospheric Administration (NOAA), with $11.8 million, does more basic research than any other part of Commerce, and essentially all of this is intramural. NOAA operates: (1) the Atlantic Oceanographic and Meteorological Laboratory and the Pacific Marine Environmental Laboratory, which do basic research in both meteorology and oceanography; (2) the Air Resources Laboratory, which is chiefly concerned with air pollution; (3) the National Hurricane and Experimental Laboratory and the National Severe Storms Laboratory; (4) the Geophysical Fluid Dynamics Laboratory, which studies the general circulation of the atmosphere; and (5) the Environmental Research Laboratories (ERL).

ERL manages all the NOAA laboratories. Selection of a laboratory director involves the Administrator of NOAA and any Assistant Administrator involved with the particular laboratory. Although laboratory programs are determined fairly rigidly, each laboratory has a small amount of seed money to permit starting promising new projects. ERL has additional seed money, which other laboratories may request. Arrangements for the Geophysical Fluid Dynamics Laboratory are interesting. Space is rented from Princeton University and a computer is rented from industry. Princeton University also receives funds for research, which permits its faculty to interact with the laboratory, but the laboratory personnel are civil service employees of ERL/NOAA.

The second largest basic research program in Commerce is that of the National Bureau of Standards (NBS). With $6.5 million estimated 1977 obligations, NBS has a large array of laboratories in Gaithersburg, Md., and a relatively small laboratory in Boulder, Colo. It reports 92 percent of its basic research as intramural. NBS is a Government bureau and its Director is appointed by the President with the advice and consent of the Senate. The Director of NBS, however, also is director of the laboratories.

[2]All such percentages in this chapter are computed from data in *Federal Funds*, Vol. XXVI (NSF 77-317), Appendices C and D, chiefly Table C-30, which is reproduced herein as Appendix D.

[3]Except as otherwise indicated, information in this and all subsequent paragraphs was obtained either from agency submissions or by informal communications from agency representatives to NSB staff.

NBS is organized into four institutes that carry out almost all its basic research.[4] The Institute for Basic Standards has facilities at Boulder as well as others in Gaithersburg. The Quantum Physics Division of the Institute for Basic Standards is the NBS component of the Joint Institute for Laboratory Astrophysics (JILA), a collaborative venture with the University of Colorado (CU) in Boulder. JILA has operated under a Memorandum of Understanding between NBS and CU since the Institute was founded in 1962. JILA's staff now numbers 150 persons, of whom 18 are NBS personnel. The total operating budget of JILA is approaching $4 million, with roughly a third of that amount provided by NBS. A chairman elected every 2 years by the senior scientists is the nearest approximation to a director. The JILA building was built by the university, with roughly half the cost funded by a grant from NSF and the remainder provided by NBS through rent payments. NSF now gives the university a substantial grant for the research operation. The rationale is that both fundamental standards and astrophysics need the same sort of new knowledge from basic atomic and molecular physics. The experiment has been very successful.[5]

As reported in the NBS section of Part I, each institute of NBS prepares its program budget, which is reviewed internally by the Director and Executive Board. The whole program is reviewed by the National Academy of Sciences (NAS). Although there appears to be much flexibility in the NBS charter, there is not so much in practice. An individual experiment can be started if the experimenter can convince his superiors in his institute that it is justified. A new Bureau initiative is much harder to launch, and involves considerable interplay with the Assistant Secretary for Science and Technology, his staff, and the hierarchy up to and including the Office of Management and Budget (OMB). On the other hand, several tasks have been mandated by Congress in 15 laws passed since 1965, frequently with no funds appropriated to carry them out. Thus, a new initiative flies in the face of unaccomplished mandated work.[6]

The program of the National Maritime Administration at its only laboratory, the National Maritime Research Center in Kings Point, N.Y., does not involve basic research to a significant degree.

[4]As this report goes to press, the Bureau is in the process of a major reorganization, which may do away with the institutes.

[5]An Evaluative Report on the Joint Institute for Laboratory Astrophysics, pp. 55-60; An Evaluative Report on the Institute for Basic Standards by the National Research Council, NAS, 1977; Communication, Chairman of JILA to NSB staff, September 1977.

[6]NBS Visiting Committee; see review by Kilata, G.B., in *Science*, 197, pp. 968-970.

Department of Defense

The Department of Defense (DOD) reports 36 percent of its $247.9 million basic research as intramural in FY 1977. The consistency of intramural performance among the services seems significant: Army 39 percent, Navy 38 percent, Air Force 39 percent. "Other DOD agencies" (presumably the Defense Advanced Research Projects Agency (DARPA) with no laboratories, the Defense Nuclear Agency with its Armed Forces Radiobiology Research Institute (AFRRI), and the Secretary's Institute for Defense Analyses (IDA)) report a 14 percent intramural figure. AFRRI is located on the grounds of the National Naval Medical Center (NNMC) in Bethesda, Md. The Director is an officer of one of the services, the billet being rotated among them. Research staff includes both uniformed and civilian professional scientists. The program is directed by a board consisting of the surgeons-general of the three services, but there is considerable flexibility to follow new and promising leads as long as the work remains within the mission. IDA is an advisory body run as an FFRDC.

Army

The Army's basic research program is estimated at $40.1 million for 1977, 39 percent of which is intramural. The Army has 32 Government-operated R&D laboratories/facilities and no FFRDC's. The medical laboratories are headed by officers of the Army Medical Corps and are staffed by both military and civilian personnel, the preponderance of the professionals being military. Programs are determined basically by three program managers under the Medical R&D Command on the basis of a Science and Technology Objectives Guide (STOG) from the Army Staff. The three research fields are: (1) potential or real hazards to personnel associated with the operation of military hardware; (2) diseases and other natural hazards of potential operating areas; and (3) medical/clinical techniques for treatment of patients. The managers assign tasks to appropriate laboratories. A laboratory can do basic research needed to support an assigned task, but usually checks back with the program manager before doing so in order to avoid duplication.

The other Army laboratories come under the Army Material Development and Readiness Command (DARCOM), where the decision is made as to whether a given laboratory will be under a civilian director with a military deputy or

under a military commanding officer with a civilian technical director. DARCOM also selects these top personnel. In either case, the laboratory is staffed chiefly by civilians, with some junior officers working at the bench as scientists or engineers and more senior officers occupying administrative positions.

Program development at DARCOM laboratories is described in the Army's submission for Part I, from which the following sentence is quoted:

> . . . Although guidance is provided for the research program in general terms, responsibility for the content of the in-house basic research effort has been delegated to each technical director of an Army Laboratory and each is responsible for the initiation and termination of basic research tasks in the laboratory.

Navy

Of all the armed services, the Navy has the largest basic research program, estimated at $115.8 million for 1977, with 38 percent intramural. Most Navy laboratories (13) report to the Director of Navy Laboratories (DNL) and serve one or more system commands (SYSCOM's). Each has a naval officer in command and a civilian technical director, both of whom are chosen by the Assistant Secretary of the Navy for Research and Development based on a personal interview with the candidate and the advice of the DNL. The laboratory director has a standardized job description that contains two options, one as technical director and another as consultant; the DNL has the authority to switch an incumbent from one of these to the other. Basic research and some applied research are grouped together as "research" in DOD budgets; the remainder of the applied research is called "advanced development." All Navy research funds are administered by the Chief of Naval Research (CNR), who allocates the available funds to the DNL, each SYSCOM, the Naval Research Laboratory (NRL), the Office of Naval Research (ONR), and the Naval Oceanographic Research and Development Activity (NORDA). The DNL divides his research and advanced development funds among his laboratories on the basis of his evaluation of their performance with their previous year's allocation. These funds—about 3 percent of their total budget—enable them to do independent research, basic or applied, at the technical director's discretion. At the end of the year, the director reports what he did with the funds provided. The SYSCOM's send part or all of their research funds to their laboratories, usually providing some degree of direction.

NRL operates quite differently. It plans a program of basic and applied research, for which it gets more research funds than all the rest of the Navy laboratories put together. A higher percentage of NRL's research money goes into basic research than is the case for most of the other Navy laboratories.

The Bureau of Medicine and Surgery (BUMED) operates six laboratories in the United States and two research units overseas. Each is headed by a medical or dental corps officer, as appropriate, and the research staff is roughly half military and half civilian. Nominations for head of a laboratory are made by the Naval Medical Research and Development Command of BUMED and are acted upon in the Office of the Chief of BUMED. Basic research funds are administered by the Command with guidance from both the CNR and a Science and Technology Objectives Guide from CNO. The objectives are transmitted to the laboratories and laboratory staff members prepare proposals in accordance with them. Proposals that survive local review are forwarded to the Command, where decisions are made as to which will be supported. Those basic or applied research proposals that are approved receive research funds for the work.

The only remaining naval laboratory is NORDA, which comes under the Oceanographer of the Navy but actually is run by the CNR under his other hat as Assistant Oceanographer for Ocean Science. The program is prepared internally and sent to Washington for review by the Oceanographer, CNR, and OPNAV, with the CNR providing the research money. The laboratory director is selected by the CNR.

Air Force

The Air Force also has a large basic research program, estimated at $82.6 million for 1977, 39 percent of which is intramural. The Air Force operates 14 R&D laboratories/facilities and 4 FFRDC's. Twelve of these laboratories are under the Director of Science and Technology (DST), Systems Command, who selects their directors. In general, there is a director and a deputy, one military and the other civilian, in either order. Both military and civilian scientists or engineers perform the research, with the majority being civilian. The Frank J. Seiler Research Laboratory at the Air Force Academy (although one of the 12 under DST) is the special province of the Air Force Office of Scientific Research (AFOSR).

Laboratory programs are prepared by each laboratory in consultation with headquarters, headquarters for basic research being the Director of AFOSR. The laboratories' programs are submitted for approval to the Air Force Staff, which, for research money, rules only on total amount.

The two remaining in-house laboratories are administered jointly by the DST and the Aerospace Medical Division. These laboratories are headed by Air Force medical officers, and the research staffs are partly military and partly civilian. The basic research portions of their programs are determined jointly by the laboratory directors and the Director of AFOSR. There is less difference between medical and nonmedical laboratories in the Air Force than in the Army and the Navy.

Of the Air Force's four FFRDC's, only M.I.T. Lincoln Laboratories and the Aerospace Corporation get any Air Force research money, and when they do, they get it from AFOSR on the basis of proposals they submit. M.I.T. Lincoln Laboratories is operated by the Massachusetts Institute of Technology for the Electronics Systems Division, and the Aerospace Corporation is a nonprofit corporation operated for the Space and Missiles Division. Both divisions are under the Systems Command.

Department of Health, Education and Welfare

The Department of Health, Education and Welfare (HEW) estimates obligations of $747 million for basic research in 1977, 20 percent of which is reported as intramural.

National Institutes of Health

The National Institutes of Health (NIH) constitute the largest portion of HEW's basic research program, with an estimated $670.2 million obligations for 1977. Of this amount, 19 percent is reported as intramural, the research being performed chiefly at the extensive NIH facilities in Bethesda, Md., known as "the campus." The Director of NIH is appointed by the President with the advice and consent of the Senate. He in turn appoints the directors of the institutes, all of which are on campus except for the National Institute for Environmental Health Sciences, located in Research Triangle Park, N.C., and the National Institute on Aging, which has its administrative offices on campus but its research facilities at the Gerontology Research Center in Baltimore, Md. There are six other field activities, whose directors are chosen by the scientific director of the controlling institute. The scientific directors of the institutes have a great deal of authority and autonomy, and their appointments by the institute directors are discussed with the Director of NIH and his staff.

The scientific atmosphere at NIH is reminiscent of a university. Each scientific director normally makes major decisions on the research program and delegates a great deal to senior scientists under him. Much of the decisionmaking with regard to field activity programs is carried out by discussion on a continuing basis rather than by direction. Each institute has an advisory council which periodically reviews its programs and those of its field activities.

NIH has one FFRDC but reports no basic research conducted there, although basic research is done at an in-house activity colocated with it.

Alcohol, Drug Abuse, and Mental Health Administration

The Alcohol, Drug Abuse, and Mental Health Administration (ADAMHA) reports that 32 percent of its $60.1 million 1977 basic research program is intramural. The directors of the three component institutes—NIMH, NIDA, and NIAAA—are appointed by the Secretary of HEW and the directors appoint their research directors.

The **National Institute of Mental Health (NIMH)** conducts its basic research at its facilities on the NIH campus in Bethesda, at St. Elizabeth's Hospital in southeast Washington, D.C., and at the NIH Animal Center in Poolesville, Md. NIMH was once an institute within NIH and the research management procedures are similar.

The Addiction Research Center in Lexington, Ky., is part of the Division of Research of the **National Institute on Drug Abuse (NIDA).** The Director of the Division appoints the Director of the Center. Although only 5 percent of its basic research program is intramural, NIDA reports important results from this. Part of the Center's program is mandated by law; the balance is proposed by the Center and approved by headquarters.

The National Institute on Alcohol Abuse and Alcoholism (NIAAA) conducts a small amount of animal work at St. Elizabeth's Hospital and some other nonclinical basic research in Rockville, Md., where permanent research facilities are planned. Some clinical research is performed in collaboration with the Veterans Administration and private hospitals, which do their portion of the work under contract to NIAAA. Negotiations are underway which would make beds available at NIH for NIAAA in-house clinical research.

The Public Health Service has many more laboratories than those described for NIH and ADAMHA, but they are reported as doing no basic research.

National Institute of Education

All of HEW's basic research in education is conducted by the National Institute of Education (NIE). Obligations for 1977 (all designated for the social sciences) are estimated at $11.9 million; about 18 percent of this is reported as intramural, mostly administrative costs of the program. NIE provides support for 17 R&D centers and educational laboratories. These are not Government activities, although they were created by the Office of Education and, in many cases, were provided buildings at Government expense. They are nonprofit operations, usually located at universities, but NIE has a continuing responsibility to fund their operation. This is accomplished by contract; changes in programs require contract modifications. Through fiscal year 1977, the research program has been determined by NIE, although in many cases this has meant that NIE directed a laboratory to continue work on a program that had been initiated by the laboratory. New legislation requires that, beginning in fiscal year 1978, NIE will change to a system more like that of NIH. Proposals will be received from the laboratories and will be evaluated by a national panel.

Department of Housing and Urban Development

The Department of Housing and Urban Development reports no basic research at this time.

Department of the Interior

Interior reports 91 percent of its $124.6 million basic research program for 1977 as intramural. The Office of the Secretary manages some of the Department's basic research, and the 29 percent reported as intramural represents management costs; the Office operates no laboratories. The same is true for the Office of Water Research and Technology, which reports 15 percent of its basic research obligations as intramural and states that none of its research is performed in-house.

Geological Survey

The largest component of Interior's 1977 basic research is the $106.4 million program of the Geological Survey, which reports 96 percent as intramural. The Survey is organized into divisions, each of which has laboratories as needed at headquarters in Reston, Va., and at two regional headquarters in Menlo Park, Calif., and Denver, Colo. In addition, the Geology Division has a center for Astrogeology in Flagstaff, Ariz., and the Topographic Division has its EROS Data Center near Sioux Falls, S. D. (EROS is the Earth Resources Observation System, which uses satellite sensors.) There are several smaller laboratories throughout the country.

Laboratory directors are selected by the appropriate division director. Program determination and budgeting are described as somewhat informal with continuous interaction between headquarters, field, and outside influences, such as other agencies and State and local governments. Budgets for field activities are prepared on the basis of this interaction and are submitted to headquarters for integration. Results of research are subject to exhaustive peer review, both in-house and externally. The Survey suffers to some extent from problems similar to those reported by NBS; the Survey lists 13 pieces of legislation in the last 9 years that have increased its responsibilities without providing corresponding increases in resources. This has eroded the very necessary long-term program. (See Chapter 7 on legislation for further discussion of this point.)

Fish and Wildlife Service

The U.S. Fish and Wildlife Service reports 87 percent of its $10.1 million basic research program for 1977 as intramural. The Service has very extensive field activities; the intramural basic research is divided among most of the 35 fish and wildlife research stations and laboratories. The directors of these activities are selected by the Associate Director for Environmental Research and his deputy. Higher grade level appointments require the approval of the Secretary. Research is not a program in itself. There are 10 resource-oriented programs, each with a program manager who funds research for his program to the extent he agrees is necessary. The manager may submit a proposal to a laboratory and if the laboratory agrees to do the work at a cost acceptable to him, he will fund it. More frequently, the laboratory will plan the research and request the appropriate program managers to fund their portions. An annual budget is worked out in this way and the laboratory director has some discretion for shifting funds during the year; any large shift has to be cleared with the program manager. Part of the Museum of Natural History of the Smithsonian Institution is an important laboratory for the Service. Service personnel have a symbiotic relationship with the Smithsonian; they use the museum's space and collections in return for curating the North American Collections in their specialties.

Bureau of Mines

The Bureau of Mines does all its basic research, estimated at $800,000 for 1977, in its 13 laboratories. The Assistant Director for Metallurgy has eight of these and the Assistant Director for Mining has five. Each is headed by a research director. When a vacancy arises, the Assistant Director makes a recommendation for filling it but the Office of the Secretary has final approval. The program of each laboratory is determined by the Assistant Director but the laboratory research director decides how to accomplish the desired result. The tasks assigned are usually applied research but the research director may do such basic work as is necessary to support it. Although he does not need prior permission, his judgment is reviewed after the fact. Some of the laboratories do little or no basic research, but the Mining Research Center in Pittsburgh, Pa., and the Metallurgy Research Center in Albany, Oreg., do more than others.

National Park Service

The National Park Service reports 37 percent of its $619,000 basic research program for 1977 as intramural. The research is done in-house when sufficient manpower is available within a park to do the work; the park itself is the laboratory. Proposals for research originate with the Park Superintendent, who may or may not have scientists on his staff. Proposals then go to the appropriate regional headquarters, where they are reviewed by the Regional Chief Scientist, who forwards those he approves to headquarters in Washington for final approval. Work is performed by a park scientist if one with the necessary qualifications is on the park staff. If not, the Regional Chief Scientist contracts for the work, usually with a university. A Regional Chief Scientist vacancy is filled by the Regional Director, who consults with the Chief Scientist in Washington on the final selection.

Bureau of Reclamation

The Bureau of Reclamation has a very small program of basic research, estimated at $70,000 for 1977, all of it currently intramural. The laboratories, located in Denver at the Engineering and Research Center, are under the Director of General Research, who reports to the Assistant Commissioner for Resource Development in Washington. Vacancies in the laboratories or in the Director's billet are acted upon by the immediate supervisor, but all higher level positions require the approval of the Commissioner of the Bureau. Suggestions for new research are encouraged from all levels of the Bureau. Decisions as to what will be done are made annually by the Research Review Committee at headquarters, which meets in Denver with the Director of General Research, the seven regional directors, and laboratory personnel.

Department of Labor

Labor has a relatively small basic research program, estimated at $785,000 for 1977; 24 percent is reported as intramural. The Bureau of Labor Statistics has done very significant basic research in the past but reports none for 1977. Labor does not operate a laboratory, but some personnel of the Employment and Training Administration and the Labor-Management Services Division are reported as performing basic research, usually in addition to other duties, including administration of contract research.

Department of State

The State Department reports no basic research, although under the Agency for International Development (AID) there is some quite fundamental work which many would call basic. AID has no in-house laboratory, however.

Department of Transportation

The Department of Transportation (DOT) also reports no basic research for 1977, although from the DOT section in Part I it is clear that it intends to do basic research at some time. DOT has seven major R&D field activities; the Transportation Systems Center in Cambridge, Mass., is highly oriented toward research and advanced technology.

Energy Research and Development Administration

The Energy Research and Development Administration (ERDA) estimated basic research obligations for 1977 of $390.7 million, much less than 1 percent of which were reported as intramural. There are several causes for this anomaly. ERDA accounting procedures were such that the program administrators were not charged to the basic research program and therefore did not appear in the intramural portion. Even if program administrators directly involved were charged, the effect would be less than that for most agencies because

about half of ERDA's basic research was in high-energy physics, a large program run by a very small staff.

Another factor was ERDA's extensive use of FFRDC's, which employ over 56,000 contractor personnel compared with less than 1,000 employees in the seven in-house laboratories. Two of the seven were formerly AEC laboratories and do no basic research. The other five were Bureau of Mines laboratories. Although they do some research that may be considered basic, it has not been reported as such because it may not fit the NSF definition; the research is principally on fossil fuels and combustion. These five, known as Energy Research Centers (ERC's) reported to the Assistant Administrator for Fossil Fuels, who selected their directors as vacancies occurred. Some ERC's have played "lead center" roles for which they have been funded at a predetermined level, including the basic research component. The rest of their funding has been handled on the basis of their annual project proposals, reviewed by the division having cognizance. The division could approve, reject, or revise a proposal, the latter procedure being by direct negotiation between division and center. The proposals as finally approved made up the budget request, which was then coordinated with the funds available. All details did not have to be spelled out in the proposals; individual basic research tasks in support of an approved objective were undertaken at the center director's initiative as long as the tasks were appropriate and could be accomplished within the approved funding level. New ideas occurring during the year could be exploited only with the cognizant division's approval and with funds provided by that division. Funds already approved for a center could not be withdrawn by a division without the Assistant Administrator's approval.

There were 20 FFRDC's listed for ERDA. They are operated by industry, universities, consortia of universities, and one by Battelle Memorial Institute, a nonprofit institution. Some are multipurpose, with everything from basic research to fabrication of prototypes and production of radioisotopes; others are single-purpose. Basic research is conducted under all these types of management. Typical management contracts run 5 years and may be renewed repeatedly.

One of the more involved situations is that of Argonne National Laboratory, a multipurpose laboratory doing basic and applied research in many fields as well as development and other tasks. It is operated by the University of Chicago under the guidance of Argonne Universities Association (AUA), a nonprofit corporation that is a membership consortium of 26 universities, including the University of Chicago. A three-way contract joined ERDA, AUA, and the University in this endeavor. A very different example is the Stanford Linear Accelerator Center (SLAC), a single-purpose laboratory doing basic research in high-energy physics under a contract between Stanford University and ERDA.

For almost every ERDA FFRDC, contract language states that the facilities belong to ERDA and the contractor hires the employees, paying them with ERDA funds. ERDA exercises supervision over the rate of pay. The contractor selects the laboratory director but the selection must have ERDA approval. The contractor's own staff administering the contract is paid by the contractor, and the contract provides for a management allowance or fee to cover such expenses.

This whole arrangement has enabled the contractor to maintain a suitable environment for research and to compete on an approximately equal basis with universities and industry for high-quality scientific staff. Basic research programs have been planned by the laboratory starting about 2 years in advance, with many details only generalized. Each cognizant division at ERDA dealt with the requests in its field, apportioning available funds. Basic research programs have remained somewhat general even when finally approved, and laboratory directors have had considerable discretion within a program, although they could not shift funds between programs.

In the case of the Fermi National Accelerator Laboratory (FERMILAB), a single-purpose laboratory operated by Universities Research Association (URA), a consortium of 53 universities, most of the research (high-energy physics) is done by visitors who are separately funded by ERDA, NSF, their home institution, or even another country. The laboratory physicists operate the 400-500 GeV proton synchrotron, work on improvements to the instrument, provide technical services to the visitors, and participate in the research program to the extent that they perform about 15 percent of it. URA is charged by its member universities and by ERDA with managing this expensive facility in an equitable manner for the benefit of the country.

To this end, the Director has appointed a committee of leading high-energy physicists, almost all from outside the laboratory, to review all proposals for research to be done there. An independent organization of those interested in the use of the facility, the Fermilab Users Organization, assists in selecting the members of this committee, which assigns a period of running time, typically a few hundred hours, and a place in the schedule to each experiment they recommend for approval. A typical experimental group will have members from several institutions, one of which may be Fermilab. The Director normally adheres to the recommendations as closely as practicable, al-

though he sometimes grants an extension of time without going back to the committee. The Users Organization elects an executive committee whose chairman is invited to meet, if he or she wishes to do so, in closed session with the board of trustees of URA at any of its meetings. This device permits the board to hear first-hand any complaints from the high-energy physics community on the way the laboratory is run.[7]

Environmental Protection Agency

The Environmental Protection Agency (EPA) reports that, in 1977, only 5 percent of its $21.2 million basic research program is intramural. EPA operates a group of four laboratories in Research Triangle Park, N.C., another group of four in Cincinnati, Ohio, and eight other laboratories. The laboratories run the total basic research program, both intramural and extramural. Each is headed by a director who is a Public Health Service officer or a civilian at about the GS-16 level. In case of vacancy the new director is selected by the appropriate Deputy Assistant Administrator (DAA), of which there are four located at EPA headquarters in Washington. Programs are developed by the laboratory directors with guidance from their DAA, who exercises final approval of the program. A director has considerable discretion to follow new leads within the scope of the approved program.

National Aeronautics and Space Administration

The National Aeronautics and Space Administration (NASA) reports that, in 1977, 49 percent of its $319.7 million basic research program is intramural. The Ames, Lewis, and Langley Centers are the largest components, followed by the Goddard Space Center and the Jet Propulsion Laboratory (JPL), an FFRDC operated for NASA by the California Institute of Technology. Considerably less basic research is done at the five remaining centers and at the National Space Technology Laboratory. Each center has a director who is appointed by the Administrator. The contractor appoints the director of JPL and sets his salary; formal approval by NASA is required in the contract. Programs of both in-house laboratories and JPL are based on research and techology objectives plans (RTOP's). These are submitted by the field to headquarters, where they are considered for approval. Directors have considerable flexibility as long as they stay within the program objectives and approved funding.

Some other basic research activities of NASA are performed under a contract with Universities Space Research Association (USRA), a nonprofit corporation that is a consortium of 51 universities. USRA operates the Lunar Science Institute (LSI) in Houston, Tex., and the Institute for Computer Applications for Science and Engineering (ICASE), which uses NASA space and facilities at the Langley Research Center. USRA also arranges peer review for several NASA intramural programs and is assisting in the collection and evaluation of proposals for inclusion in two space shuttle experiments, the Atmospheric Cloud Physics Laboratory and the Materials Processing in Space Project. LSI, with an annual budget of $1 million, is hard to distinguish from an FFRDC and hence is included here. Directors of LSI and ICASE are appointed and their salaries set by USRA; NASA has not retained any veto authority under the contract. Programs are developed by the institutes and submitted to NASA for approval.[8]

National Science Foundation

The National Science Foundation (NSF) has a basic research program estimated at $605.8 million for 1977, 12 percent of which is reported as intramural. The intramural portion represents the administrative costs of operating the extramural program, since under existing law NSF is not permitted to operate any laboratories. NSF does have six FFRDC's, which performed 7 percent of NSF's basic research in 1977. Visiting investigators at an FFRDC may be funded by NSF or by another agency.

One FFRDC is the National Center for Atmospheric Research (NCAR), operated by the University Corporation for Atmospheric Research (UCAR), a consortium of 45 universities. NCAR includes a High Altitude Observatory (HAO) a few miles from its main laboratories and offices in Boulder, Colo., and the National Scientific Balloon Facility in Palestine, Tex. NSF's other FFRDC's are all observatories that provide the Nation's astronomers and others with unique facilities for research. Chief among these are the

[7]Material on ERDA's FFRDC's is taken from the operating contracts and discussions with officers of the consortia.

[8]Information based on "A Brief Introduction to Universities Space Research Association," USRA, November 1977, and conversations with USRA corporate officers.

1,000-foot radio telescope and radar at Arecibo, Puerto Rico, a facility operated by Cornell University; highly steerable radio telescopes, from 36 to 300 feet in diameter, operated by the National Radio Astronomy Observatory (NRAO) under another consortium of universities, Associated Universities, Incorporated (AUI); and an array of optical telescopes at three facilities under still a third university consortium, the Association of Universities for Research in Astronomy (AURA).

At Arecibo, visiting users currently are getting 68 percent of the observing time. At NRAO's main facility in Greenbank, W. Va., the policy is to give visitors at least 60 percent of the observing time; at latest review they were actually getting 71 percent. NRAO's Very Large Array (VLA), under construction at Soccoro, N. Mex., eventually will consist of 27 antennas, each an 82-foot dish that can be moved as desired along three radiating sets of tracks, each about 13 miles long. Used in this way, they will have the collecting power of a dish 426 feet in diameter but the resolving power of one about 25 miles in diameter.

AURA's oldest FFRDC is the Kitt Peak National Observatory (KPNO), which includes the world's largest solar telescope, a solar vacuum telescope, and several other optical telescopes including one 4 meters in diameter, which in this country is second only to the 5-meter telescope at Mount Palomar. NRAO has a 36-foot millimeter-wave radio telescope at Kitt Peak and there are some university telescopes there also. AURA also operates the Cerro Tololo Inter-American Observatory (CTIO) in the Chilean Andes, which is equipped with several telescopes, including a 4-meter one that was funded jointly by NSF and the Ford Foundation. At both KPNO and CTIO visiting observers get 60 percent of the observing time, and at CTIO up to 10 percent of the total may be used by visiting scientists from Central and South America.[9] The newest of the NSF FFRDC's is the Sacramento Peak Observatory (SPO) in Sunspot, N. Mex., recently transferred to NSF from the Air Force; AURA is the interim manager.

All the instruments at SPO are designed for observing the sun; the large vacuum tower telescope and a 40-centimeter coronagraph, the largest in the United States, are the most spectacular. Because an operating contract has not yet been negotiated it is not known how much use of the facilities will be shared with visiting scientists. NCAR's HAO constructed at least two of the coronagraphs at SPO and uses one jointly with SPO staff. NASA also has a solar spectrograph at SPO, which is used to support operations in space.[10]

The contractor selects the director of each FFRDC, subject to the approval of the Director of NSF, who also approves the directors' salaries. Programs are developed on a long-range basis by the laboratory/observatory and the program managers at NSF. A submission is made annually to NSF for the work planned for the coming year in accordance with the program developed. The program manager has final approval for inclusion in the NSF budget. The contractor has considerable discretion within the bounds of agreed objectives. When the program manager plans to fund an investigator who will be using a field facility, this arrangement is usually negotiated in advance. Contractual business must be conducted between NSF and the contractor; scientific dialogue is ongoing at lower levels.

Smithsonian Institution

The Smithsonian estimates that 93 percent of its $31 million Federal obligations for basic research in 1977 is intramural. Most of this research is done either at or from the establishment in Washington, D.C., which houses the national collections. The collections themselves are the working material for a great deal of this research. The National Zoo also has a breeding station in Virginia. The Smithsonian's largest outside laboratory is the Smithsonian Astrophysical Observatory (SAO), which is housed in the Center for Astrophysics, in Cambridge, Mass., a joint venture of the Smithsonian and Harvard University. The Director of SAO is also the director of the Center and is selected by the Secretary with the approval of the Harvard Board of Regents and the Smithsonian Board of Regents.

Other Smithsonian laboratories are the Tropical Research Institute in the Canal Zone, the Radiation Biological Laboratory in Rockville, Md., and the Chesapeake Bay Center for Environmental Studies, also in Maryland. Each of these has a director selected and appointed by the Secretary, although all such appointments are referred to the Regents, as are other important matters. The Regents are the Chief Justice of the United States (Chancellor), the Vice President of the United States, three members of the Senate, three members of the House of Representatives, and nine citizen members.

[9]Lynds, B. T., *The National Observatories* (AURA: 1976).

[10]"Sacramento Peak Observatory," a visitors' pamphlet published by the Observatory, 1977.

Veterans Administration

For 1977, the Veterans Administration (VA) reports a basic research program of $9.3 million, all of which is intramural. This work is performed in the VA hospitals, usually by clinicians caring for patients. The details of the VA's somewhat complicated but quite flexible system for managing this program are reported in its section in Part I. The principal characteristic of the system is its decentralization.

Summary

A significant portion of the Nation's basic research is performed in facilities operated by the Government or operated by contractors on behalf of the Government. Some of the FFRDC's of ERDA (now DOE) and all those of NSF are essentially basic research facilities, as are JILA (a joint activity of NBS and the University of Colorado), some of the Smithsonian's activities, and NOAA's small Geophysical Fluid Dynamics Laboratory at Princeton University. Some other laboratories, such as some of NASA's and the Geological Survey's, and Navy's NRL, devote a significant part of their funds to basic research. But for most Federal R&D installations (there were about 500 listed in 1969), basic research is a small or nonexistent part of their responsibilities.[11]

There is great variation in the degree to which authority over basic research is delegated to the field. In the case of NSF, the Smithsonian, the high-energy physics program of ERDA/DOE, and to some extent NASA, the agency mission itself is to do the basic research. Based on the relative numbers of Government personnel involved, it appears that ERDA has delegated more responsibility to FFRDC's than NSF has in program matters, although the reverse is true in management matters. Where the mission of the agency implies greater constraints, there still is great variation in laboratory management, all the way from complete freedom to do what is necessary to achieve an agreed objective within available funds to such tight constraints in some cases that it is difficult to see how truly basic research could be accomplished. Great variations can occur even within a single agency—witness the greater constraints imposed by headquarters on Army and Navy medical laboratories than on military hardware laboratories; or compare NIE with NIH, both in HEW.

The vision and attitude of the director or technical director of an R&D installation have great bearing on the quality of basic research that will be performed there. But at laboratories that are primarily geared to development, it is not at all clear that basic research is a major consideration when such a position is being filled. It is apparent that such selections are taken quite seriously in most agencies. The situation is complicated, however, by the great differences in scientific talent available at agency headquarters. Although some may lack anyone in the higher echelons with scientific background, there is evidence of a high degree of sophistication in other agencies, where very high-level executives with long research experience have been personally involved in filling such positions.

[11] *Directory of Federal R&D Installations for the Year Ending June 30, 1969*, NSF 70-23, 1970.

CHAPTER 2

AGENCY SUPPORT OF BASIC RESEARCH IN INDUSTRY

Federal obligations (current dollars) for support of basic research in industrial firms in FY 1977 are estimated at $201 million (see Table 3 and Figure 4 in Introduction). This is only 7.3 percent of the estimated total Federal obligations for basic research in FY 1977.

Industrial firms, as might be expected given their emphasis on applied and developmental work, have trailed other performers in Federal obligations for basic research. Industry's share of the total Federal basic research activity has dropped from a high of 12.6 percent in 1968 to 7.3 percent in 1977. Obligations to industry dropped during the 1968-76 period by an average of 4.4 percent annually, but there has been a turnaround since then. Estimated obligations are up 32.2 percent in 1977 over 1976 and are projected to rise another 24.4 percent in the 1978 budget.

Federal agency support of basic research in industry should be looked at in the context of the overall conduct of R&D by industry itself. Expenditures for R&D in the United States were expected to reach a level of about $41 billion in 1977. About 68 percent of this total ($28 billion) represents R&D performed by industry; industry was the source of 43 percent of the funds expended ($18 billion). Basic research represents only 3 percent ($790 million) of total funds expended by industry for R&D in 1977; this is a declining percentage over the years and appears to reflect increasing emphasis on product and process improvement.

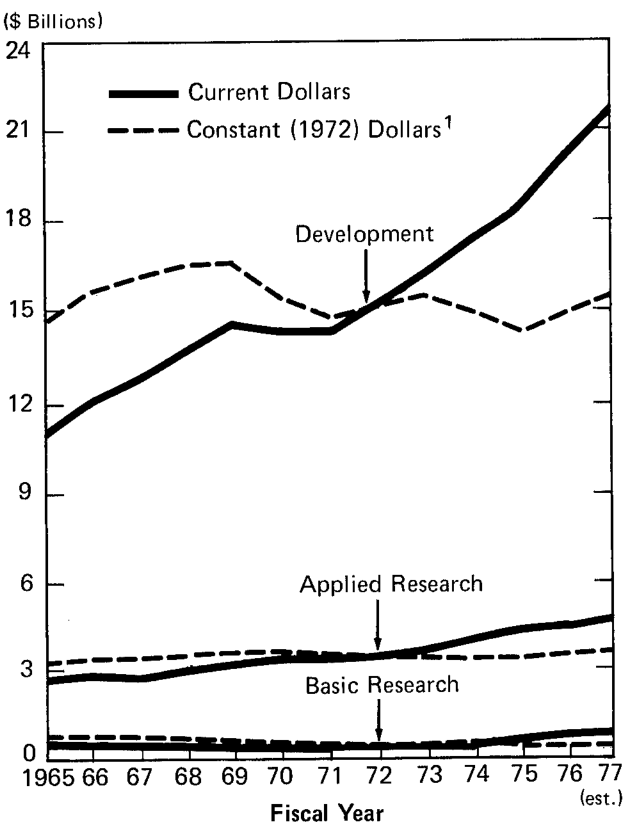
The trends in the levels of basic research, applied research, and development performed by industry are shown in Figure 2.1. Performance of applied research and development shows an almost uninterrupted growth since 1965 in terms of current dollars; however, in terms of constant 1972 dollars, expenditures for applied research are almost level and drop significantly for development from a peak in 1969. Conduct of basic research reached an estimated total of $790 million (in current dollars) in 1977; there was a decline during the period 1968 to 1972. In constant 1972 dollars, a peak of over $800 million for conduct of basic research was reached in 1966; it has been declining since then, reaching a fairly constant level of about $550 million for the period 1975-1977.

Fund totals (in both current and constant 1972 dollars) for basic research, applied research, and development performed by industry during the period 1965-1977 are given in Table 2.1.

Basic Research Performance by Type of Industry (1975)

The chemical industry outranked all others in performance of basic research in 1975, expending $276 million out of the industry total of $702 million (see Appendix E). The two largest components of basic research in the chemical industry were in industrial chemicals and in drugs and medicines. Other major industrial performers of basic research were in electrical equipment and communication with $193 million; aircraft and missiles with $47 million; petroleum refining and extraction with $36 million; machinery (including office, computing, and accounting machines) with $29 million; food (and kindred products) with $25

Figure 2.1—Industrial R&D expenditures, by character of work: 1965-1977



[1]Based on GNP implicit price deflator.

SOURCE: Division of Science Resources Studies/STIA/National Science Foundation.

Table 2.1—Industrial R&D expenditures by character of work, 1965-77

[Dollars in millions]

Year	*Basic research*		*Applied research*		*Development*	
	Current	*Constant*[1]	*Current*	*Constant*[1]	*Current*	*Constant*[1]
1965	$592	$797	$2,658	$3,576	$10,935	$14,713
1966	624	813	2,843	3,704	12,081	15,739
1967	629	796	2,915	3,689	12,841	16,250
1968	642	778	3,124	3,783	13,663	16,547
1969	618	713	3,287	3,790	14,403	16,609
1970	602	659	3,426	3,750	14,034	15,361
1971	581	605	3,413	3,554	14,317	14,910
1972	579	579	3,471	3,471	15,333	15,333
1973	612	578	3,739	3,534	16,570	15,662
1974	677	582	4,160	3,574	17,562	15,086
1975	702	552	4,411	3,466	18,427	14,481
1976 (est.)	740	553	4,675	3,495	20,085	15,017
1977 (est.)	790	559	5,050	3,575	21,910	15,521

[1] 1972 dollars based on GNP implicit price deflator.

Source: Division of Science Resources Studies/STIA/NSF

million, and professional (and scientific) instruments with $14 million. These seven categories accounted for 88 percent of the basic research performed by industry.

Basic Research in Industry by Field of Science (1975)

Basic research performed by industry in 1975 was concentrated in the physical sciences and in engineering. The physical sciences accounted for $316 million (45 percent) out of a total of $702 million and engineering for $192 million (27 percent). Basic research in the life sciences totaled $129 million (18 percent). (See Table 2.2.)

Slightly more than 4 percent of all basic research performed by industry in 1975 was carried out by firms with fewer than 1,000 employees. Almost 60 percent was carried out by firms with 25,000 or more employees. This concentration of basic research performance in the largest firms holds true for the major scientific disciplines except the life sciences, where the greatest concentration occurs in firms having between 10,000 and 25,000 employees.

Basic Research in Industry by Source of Funds (1975)

Only 22 percent of the funds used by industry in 1975 in the conduct of basic research came from Federal sources; this total of $154 million (see Appendix F) was in sharp contrast to the $548 million in company funds expended for basic research. Federal support of basic research in industry was primarily in electrical equipment and communication ($66 million); chemicals and allied products ($53 million); aircraft and missiles ($15 million); and nonmanufacturing industries ($12 million). These four industrial categories accounted for 95 percent of total Federal funds expended for basic research by industry.

Agency Support of Basic Research in Industry (1977)

The principal Federal agency sources of support for basic research in industry in FY 1977 were the Department of Defense ($55 million), the National Aeronautics and Space Administration ($84 million), the Energy Research and Development Administration ($48 million), and the National Science Foundation ($10 million). Totals for ERDA and NSF include a combined total of $49 million for FFRDC's administered by industrial firms (see Appendix D).

Federal R&D obligations to FFRDC's in FY 1977 were estimated to be $2,509 million (see Appendix G, Table C-8). Forty-two percent of these funds ($1,062 million) went to industrial firms for administration and operation of FFRDC's; these included eight FFRDC's which were funded by ERDA.

Only $49 million (4.6 percent) of the $1,062 million going to industrial firms for operation of FFRDC's were obligated for basic research. This

Table 2.2—Funds for basic research, by field of science and company employment size, 1975

[Dollars in millions]

Total Employment		*Under 1,000*	*1,000-4,999*	*5,000-9,999*	*10,000-24,999*	*25,000 and over*
Total	$702	$31	$60	$81	$115	$415
Physical Sciences	316	6	21	44	49	195
Chemistry	231	n/a	n/a	41	43	124
Physics	n/a	n/a	n/a	n/a	6	n/a
Astronomy	n/a	n/a	n/a	n/a	n/a	n/a
Mathematics	12	n/a	n/a	n/a	n/a	11
Environmental Sciences	11	3	n/a	n/a	n/a	4
Atmospheric Sciences	4	n/a	n/a	n/a	n/a	n/a
Geological Sciences	6	n/a	n/a	n/a	2	3
Oceanography	1	n/a	n/a	n/a	n/a	n/a
Engineering	192	15	21	9	12	135
Life Sciences	129	n/a	n/a	27	47	41
Biological Sciences	90	n/a	n/a	15	37	n/a
Clinical-Medical Sciences	38	n/a	n/a	12	10	n/a
Other Sciences	41	5	2	n/a	n/a	30

[1] Sum of detail may not add to total or subtotals due to rounding.

n/a—Not separately available but included in higher level totals.

Source: Survey of Industrial Research and Development, U.S. Bureau of the Census (1975)

Table 2.3—Federal funds obligated for industry-administered FFRDC's, 1974-1977

[Dollars in millions]

	1974	*1975*	*1976*	*1977*
Total R&D funds	$593	$729	$849	$1,062
Basic research	23	33	43	49
Applied research	75	108	139	173
Development	495	588	667	840

Source: *Federal Funds,* Vols. XXIV (NSF 75-323), XXV (NSF 76-315), XXVI (NSF 77-317)

is in sharp contrast to the 1977 basic research obligations of $315 million in the FFRDC's administered by universities and colleges.

The trends in support of basic research in industry-administered FFRDC's for the period 1974-1977 are shown in Table 2.3.

In current dollars, Federal obligations for basic research in FFRDC's administered by industrial firms more than doubled in this 4-year period. The $49 million is approximately 25 percent of Federal support of basic research in industry in 1977, totaling $201 million. It is noteworthy that, while industry received $201 million, it contributed $143 million itself for basic research in universities, colleges, and other nonprofit institutions.

CHAPTER 3

AGENCY SUPPORT OF BASIC RESEARCH IN UNIVERSITIES AND COLLEGES

The Federal Government through its agencies has supported basic research in universities and colleges at a higher level than it has in industry, nonprofit institutions, or its own laboratories. Nearly one-half of all Federal funds obligated for basic research in 1977 was for work done in universities (see Tables 3 and 4 and Figure 4 in the Introduction).

For 1977, Federal obligations in current dollars for basic research were estimated to be $2,755 million, of which $1,290 million was for research in universities and colleges and $315 million for that in associated FFRDC's. Universities and colleges accounted for 47 percent of total estimated Federal basic research obligations in 1977 (FFRDC's, 11 percent). This contrasts with the 1968 figures of 43 percent for universities and colleges and 13 percent for FFRDC's (see Table 4, Introduction). In current dollars, the average annual gain in obligations for universities and colleges was 5.4 percent in the 1968-1976 period. This annual gain increased to 13.5 percent in 1977 and is projected at 8.4 percent in the 1978 budget. Associated FFRDC's registered a 3.0 percent average annual rise over the 1968-1976 period and have exceeded that rate over the past 2 years: 10.9 percent for 1977 and 10.2 percent (projected 1978 budget).

The statistics describing basic research funding are illuminating not only as to allocation by performing agency or institution but also as a record of overall Federal support of university basic research efforts. Since World War II, for instance, support of basic research and the cost of such work have increased greatly, especially in universities. Between 1953 and 1977, the increase in Federal support (in current dollars) for basic research in universities was about 25 fold; in industry it was 5 fold.[1]

Almost all of the basic research funds allocated to the "universities and colleges" category in the tables actually go to universities and not to colleges. Of all universities, over 85 percent of the funds go to less than 100. Thus, the basic research activities funded by the Federal Government are concentrated in a relatively few universities.

The university is a logical place to conduct basic research as it has science faculties capable of and involved in the most fundamental research. Associated with them are talented and stimulating graduate students available as research assistants, and, over the years, libraries, computers, and some of the most sophisticated and complex research and support facilities have been constructed at these institutions.

The University Role

Universities thus have become major centers of basic research. Unlike most other technologically advanced nations, the United States has not established an elaborate system of national laboratories, institutes, and centers separate from universities to conduct basic research. There are major Federal and industrial R&D laboratories separate from universities, but, with some exceptions, they are not significantly involved in basic research. The conduct of basic research by university faculty scientists with participation by advanced students not only serves the immediate need for research but also provides the highest level of educational opportunity and continuity in the sciences. During the last century it has become an essential part of the U.S. way of doing basic research and at the same time providing advanced education in the sciences.[2]

This chapter is confined to viewing how the agencies involve universities in the conduct of their research and includes comments on the effectiveness and health of this relationship. A number of the questions directed to the mission agencies addressed their relationships with universities in general. The agencies' descriptions of their role in basic research in Part I occasionally include comments on university relationships; these were also used in preparing this chapter. The agencies differ in their manner of involvement with universities as well as in their missions. Thus, generalizations on how Federal agencies relate to universities are difficult to make. Similar-

[1]Calculated from data in *National Patterns of R&D Resources, Funds, and Manpower in the United States, 1953-1977*, NSF 77-310, pp. 24-25.

[2]Wolfle, Dael L., *The Home of Science: The Role of the University*. The Carnegie Commission on Higher Education (New York: McGraw-Hill, 1972).

ly, universities vary in their manner of performing basic research for the Federal Government. At any one time, there are thousands of ongoing projects and thousands of individual investigators at work. These projects may be conducted by individual investigators, teams of investigators, or consortia of universities—and in large laboratories, ships and stations, or national laboratories managed by university consortia (see Chapter 1).

Most R&D supported by the Federal Government is in applied and developmental work. Universities are not heavily involved in either. In 1977, of research classified as applied, universities performed only 21 percent of the total supported by Federal agencies, and of activities classified as development, they performed only 2 percent.

Much basic research in universities is supported by grants made for projects proposed to the funding agency by investigators. NSF and NIH allocate almost half the total Federal money spent on basic research and with DOD, DOA, Interior, ERDA, and NASA supply over 96 percent (see Figure 3 and Table 2 in the Introduction). The allocations of NSF and NIH primarily are in the form of grants rather than contracts, and are made to investigators in response to unsolicited proposals.[3]

The agencies recognize the need for basic research to advance human knowledge. They also believe that universities provide a sustaining environment for the conduct of such work and assert that high quality work is done in universities. When listing their basic research achievements and contributions supported by their agency, officials cite the awards, prizes, and recognition their investigators have received. They mention these with pride and as proof that their peer review process is effective in selecting outstanding scientists to support. Much of the work cited was done by university faculty scientists.

It is important to note that research, whether federally supported or not, is a normal activity of a university science faculty. Faculty research is supported in substantial part by State or local governments. In most universities the salary paid university faculty members, in or out of the sciences, is for research and scholarship in their respective disciplines as well as for teaching.

Agency Concerns

The relationship of the Federal Government to universities has been debated since the country was founded (see Part III). The agencies remain concerned about the health of the university science establishment, especially because of the reduction over the past decade in Federal programs designed to support university institutional capacities. This reduction is viewed as adverse to agency objectives and is frequently mentioned as an important concern.

In recent years repeated attempts have been made to formulate a system of general Federal support for universities in recognition of their role as partners in science. Legislation proposed and debated intensively in the 1960's would have developed a formula to recognize the universities' role in science education and sponsored research and would have funded them according to their efforts and contributions as institutions. DOD, NASA, NIH, and NSF have had at one time or another formula grant systems to recognize the general costs incurred by universities as they become involved in federally supported science education and research. Since the early 1960's, substantial funds have been provided for (1) fellowships and training grants, (2) major equipment and special laboratories, (3) university science development, and (4) university science buildings or remodeling. By 1977 these programs had been largely reduced or terminated.

The agencies are worried about the reductions in institutional programs and how they are affecting the university capacity to respond to Federal needs. Among the agency concerns specifically mentioned are:

- Quality and adequacy of the science manpower supply. The need for more and better trained and educated people as well as places for them in the agencies is regarded as necessary to accomplish their missions. The managers of Federal laboratories are especially concerned about the manpower issue.
- Instability of funding. Basic research is long-term and needs continuity of funding. "Stop-and-go" funding does not insure a continuing high-quality scientific capability.
- The increasing complexity of record keeping and reporting and the increasing requirements of accountability. Good relationships with university scientists are most difficult to maintain in the midst of a tangle of "red tape," the agencies say.
- The deterioration of any systematic and long-term general support of university research. Agency administrators mention this frequently. They seek to renew the level of effort existing in the 1960's by NSF, NIH, DOD, and NASA and to have university grants, special development programs, and laboratory or departmental funding. Many agencies

[3] A solicited proposal is one in response to an agency's invitation to undertake specific work; it usually results in a contract and is most often applied in nature. (See Chapter 5 regarding management of research by agencies.)

had such funding programs in the past decade and would like them again. The past programs provide models on which similar but more effective programs could be based.

- The shift away from basic to applied work. Many respondents commented and expressed concern about selection of short-term over long-term projects, and low-risk projects over riskier fundamental research. Some agency research managers object to such shifts in emphasis in their own laboratories as well as in the universities.

Concern from Outside the Agencies

Three recent reports relate to and in most respects are consistent with the above concerns expressed by the agencies. They are the Smith-Karlesky report,[4] the Eighth Annual Report of the National Science Board,[5] and the Report of the Defense Science Board.[6]

Smith and Karlesky observe that there is a weakening of the financial base of the universities due to recent national economic trends. This, they predict, will pose problems for future research activity in these institutions. Their other findings include:

- A notable shift away from basic research to applied and mission-oriented research, and from risk-taking to relatively safe and more predictable lines of inquiry;
- Neglect of less highly ranked research universities and departments, a trend which may also affect leading university research centers in the years ahead;
- Slowing down of the strong momentum of America's basic science research effort and the training of young scientists;
- Strained relations between Federal and State governments and the universities, which impedes scientific effectiveness;
- Narrowing of the number of first-rank research centers, leaving the national research system more stratified and less pluralistic;
- An atmosphere of rapid change surrounding important choices about the research role of the universities in the next decade.

[4]Smith, Bruce L. R. and Joseph J. Karlesky, *The State of Academic Science: The Universities in the Nation's Research Effort* (Change Magazine Press: New York, 1977).

[5]*Science at the Bicentennial - A Report from the Research Community*, Report of the National Science Board/1976 (GPO: Washington, 1976).

[6]*Report of the Defense Science Board Summer Study Group on Fundamental Research in Universities*, Office of the Director of Defense Research and Engineering (Department of Defense, October 1976).

In the National Science Board's Eighth Annual Report, administrators and officials of Federal laboratories and agencies as well as persons from industry and universities concerned with research were surveyed on the critical issues facing science in the foreseeable future. The four dominant issues that emerged were;

- dependability and stability of funding;
- vitality of the research system and the manpower supply;
- freedom to conduct basic research and unfettered investigations and freedom from the pressure to do applied research; and
- lack of public confidence in science and technology.

The Report of the Defense Science Board concludes that several types of institutional funding should be implemented. In transmitting this report to the Secretary of Defense, Dr. Solomon J. Buchsbaum, Chairman of the Defense Science Board, notes

> . . . . a need for the Department of Defense to reestablish and stimulate its relationship with the university science community. . .

and adds that, "a major source of new innovative ideas for future defense needs resides in our university community." Buchsbaum notes that many of the concerns and recommendations are very similar to those expressed in the National Science Board's report.

Research Environment

Nothing paralleling the university situation in shortage, obsolescence, and disrepair of equipment (as noted by Smith and Karlesky) was reported for the Federal laboratories by the agencies (for such items as computers, laboratory staff, supplies, equipment and central shops, and administrative services). The agencies generally feel that equipment and support staff are adequate; however, they worry about position limitations that result in too few scientists and technologists to accomplish their missions fully. In contrast, universities have more students and investigators ready to do research in some areas than are now involved or supported. In summary, the universities are long on people and short on support and facilities. Just the reverse seems to be true for Federal laboratories.

The universities, it should be noted, face a special problem in undertaking Federal R&D grant projects. The grant budget is confined to the project and for the most part must largely be spent according to itemized budget lines, such as travel, supplies, salaries, and equipment. Once allocated,

funds cannot be transferred easily from item to item. Equipment for federally funded research projects can be included in the project budget. But equipment funds are weighed in competition with other needs such as salary and wages. When the overall grant amount is reduced—as is frequently the case because of shortage of funds—equipment items as well as graduate assistant support are often squeezed out. Moreover, major items of equipment are often needed for entire research departments or groups and not just for a single project. Since they are often very expensive, they cannot be justified by any one project. Thus, the university departmental, institute, or central laboratories, as such, often fall short of their needs for essential equipment. Agency programs now seem to be needed that would respond to broad university requirements for major research equipment without subjecting those requirements to direct competition with project grant funds.

Internal Versus External Research

Many agencies support basic research both in their own and in outside laboratories. Universities do the majority of this outside work. The decision to do the work inside or to select a university proposal is a difficult one. Some agencies, such as NIH and DOD, solve the problem administratively by establishing specific budgets or levels for outside research. Others, using a single research budget, select the best performer without regard to the affiliation of the investigator. NSF, on the other hand, supports only outside investigators and almost exclusively those in universities. Agencies usually do applied research in-house; they spend only a small portion of their budgets in universities for such work. Some agencies support very little basic research in universities but maintain university affiliations in other ways. The National Bureau of Standards, for example, uses university people on its advisory and review committees and is closely affiliated with a laboratory in a university (the Joint Institute for Laboratory Astrophysics (JILA) at the University of Colorado).

Deciding where and how to do research is especially complex in agencies supporting the whole range of research—basic, applied, and developmental—with both inside and outside performers. The Department of Agriculture is one example. Besides its own laboratories, it has cooperative ones with States (located most often in land-grant universities). It supports work in industry and by individual scientists doing both basic and applied work. In addition, the Department is initiating a competitive grants program for basic research. DOD, ERDA, and NIH have similar problems and apply a wide variety of management techniques as they deal with universities in this complex situation.

Decisions to do work in or out of agency laboratories may be influenced by the need to keep agency personnel employed and laboratories utilized. When funds are short, therefore, outside work is threatened. As agency budgets fluctuate, this produces the stop-and-go funding phenomenon that affects university work most directly. Both agency and university officials regard it as having an especially adverse impact on the conduct of basic research.

Many large, costly, and complex Government-owned and supported laboratories are operated for ERDA by consortia of universities (see Chapter 1). Some are on a campus, with faculty members from several universities holding joint appointments in the laboratory and in a university. The programs in the major accelerator laboratories, where most of the Nation's high-energy physics work is done, for instance, are carried out by diverse visiting university groups as well as permanent laboratory scientists and staff. On occasion, NSF, DOD, NIH, and NASA also may support the individual scientists who work in these ERDA laboratories. The basic research is determined by the nature of the laboratories and a complicated set of decision processes. These involve both agency and external university scientists in a very cooperative but complex way. The same composite mix of university and Federal administrative and scientific personnel exists in the NSF-funded FFRDC's in radio and observational astronomy and atmospheric research.

Relevance

In selecting projects for support, questions of relevance are constantly applied. Although some agencies apply a rigorous mission test of relevance, other agencies accept proposals in disciplines considered related to the agency mission; DOD has supported much work in pure mathematics, for instance. NSF asks only the relevance to progress in science. Agency laboratories often require mission relevance for basic research and seek relevance to applied problem solving. In university work, mission relevance is required but less critically applied. Under the Mansfield amendment, DOD was required to deny support for any work not demonstrably related to mission. This same prohibition has been applied variously by other agencies, allowing or encouraging them

to reject a host of university research proposals that were supported previously. The effects of the Mansfield amendment are still being felt. The amendment is interpreted variously, with many agency research managers desiring to apply the relevance test more loosely or not at all when considering basic research proposals. University scientists may also feel they must justify the relevance of proposed projects.

The ERDA discussion on "sustaining basic research" in Part I contains the admonition: "The rhetoric of relevance can lead to damaging constraints." ERDA identifies five types of relevance and describes how each type relates to research.

CHAPTER 4

AGENCY SUPPORT OF BASIC RESEARCH BY FIELD OF SCIENCE

Federal support of basic research has shifted significantly by field of science over the past decade (see Tables 4.1 and 4.2). The actual obligations (in current dollars) are given for 1968-1976; those for 1977 and 1978 are estimated. The life and physical sciences are dominant throughout the decade; life sciences received approximately $1,007 million, or 37 percent of the $2,755 million total for 1977, and physical sciences, approximately $806 million, or 29 percent.

The relative growth of Federal support of basic research in the 1968-1977 period is shown in Table 4.3 and Figure 4.1. Different growth rates over this period can be seen: the life sciences (73.9 percent), environmental sciences (98.0 percent), engineering (71.8 percent), social sciences (67.2 percent), physical sciences (34.6 percent), and mathematics and computer sciences (17.9 percent). Support for psychology, treated as a field separate from both the life and social sciences, decreased by 3.6 percent in this period.

An earlier study done for NSF relates the proportional shift in funding toward the life sciences and away from the physical sciences to shifts in the distribution of Federal R&D funding among the different agencies. The authors only analyzed the funds going to universities and colleges, but because the academic sector is the principal performer of basic research, their observations are relevant:

> One development related to the shift in agency funding is a corresponding shift in the funding of different science fields. Because the research support by DOD, ERDA, and NASA has proportionately decreased and that of HEW and NSF has increased, federal sponsorship has shifted from physical science and other related fields to the life sciences.[1]

This larger base of support for the life sciences, the study notes, has been "stimulated by heightened national emphasis on cancer research." In 1977 support for the life sciences subfield of bio-

[1]Smith, Bruce L. R. and Joseph J. Karlesky, *The State of Academic Science: The Universities in the Nation's Research Effort* (Change Magazine Press: New York, 1977), p. 32.

Table 4.1—Federal obligations for basic research by field of science, FY 1968-78

[Dollars in millions]

	Fiscal years										
	68	*69*	*70*	*71*	*72*	*73*	*74*	*75*	*76*	*77 (est.)*	*78 (est.)*
Total[1]	$1,721	$1,779	$1,762	$1,779	$1,974	$2,001	$2,039	$2,279	$2,425	$2,755	$3,012
Life sciences	579	539	554	574	668	669	737	797	878	1,007	1,058
Physical sciences	599	662	589	582	625	618	604	702	722	806	911
Environmental sciences	199	235	256	280	291	299	320	339	355	394	438
Engineering	156	151	180	169	185	204	188	234	240	268	297
Social sciences	61	71	64	70	80	78	73	73	85	102	113
Mathematics and computer science	67	56	58	51	63	57	49	59	70	79	88
Psychology	55	53	56	44	54	46	49	60	44	53	57
Other sciences	4	11	4	9	9	28	16	15	33	46	49

[1] Detail may not add to totals because of rounding.

Source: Division of Science Resources Studies/STIA/NSF

Table 4.2—Share of Federal obligations for basic research, by field of science and subfield, FY 1977

[Dollars in millions]

Field of Science	*$ (est.)*	*% of Total*
Life sciences	1,007	36.55
Psychology	53	1.92
Physical sciences	806	29.26
Astronomy	180	
Chemistry	203	
Physics	416	
Other	8	
Environmental Sciences	394	14.30
Atmospheric	128	
Geological	155	
Oceanography	100	
Other	10	
Mathematics and computer sciences	79	2.87
Engineering	268	9.73
Social sciences	102	3.70
Other sciences	46	1.67
Total	2,755	100.00

Source: Division of Science Resources Studies/STIA/NSF

logical sciences ($818 million) was greater than that for all of the physical sciences combined ($806 million).[2]

An analysis of the agencies' distribution of support for the seven fields of science reveals a tendency (in most agencies) to concentrate resources in a few fields.[3] In 1977 only one agency, NSF, provided $5 million or more in support for each of the seven fields. DOD provided this level of support to six fields; HEW to five; Agriculture, ERDA, and NASA to four; Interior and Smithsonian to three; and Commerce and EPA to two. All other agencies provided the bulk of their support in a single field.

Agency Support by Field of Science

The four fields of science receiving the most basic research support from Federal agencies in FY 1977 were the life sciences, physical sciences, environmental sciences, and engineering.

Life Sciences

The life sciences accounted for $1,007 million, or 37 percent of the total for all basic research support. Three agencies furnished 89 percent of FY 1977 Federal support for basic research in the life sciences. HEW provided $642 million, or 64 percent of all life sciences support—primarily through the National Institutes of Health. Agriculture was next with $138 million, or 14 percent, and NSF followed with $113 million, or 11 percent.

Physical Sciences

Total basic research support in the physical sciences amounted to $806 million, or 29 percent of all basic research support in FY 1977. This support was more evenly divided among the agencies. Of the top three supporting agencies (responsible for 82 percent of the total), ERDA provided $298 million (37 percent), NASA, $198 million (25 percent), and NSF, $165 million (20 percent).

Table 4.3—Comparison of trends in Federal obligations for basic research, by field of science and subfield, FY 1968, 1977, and 1978.

[Dollars in millions]

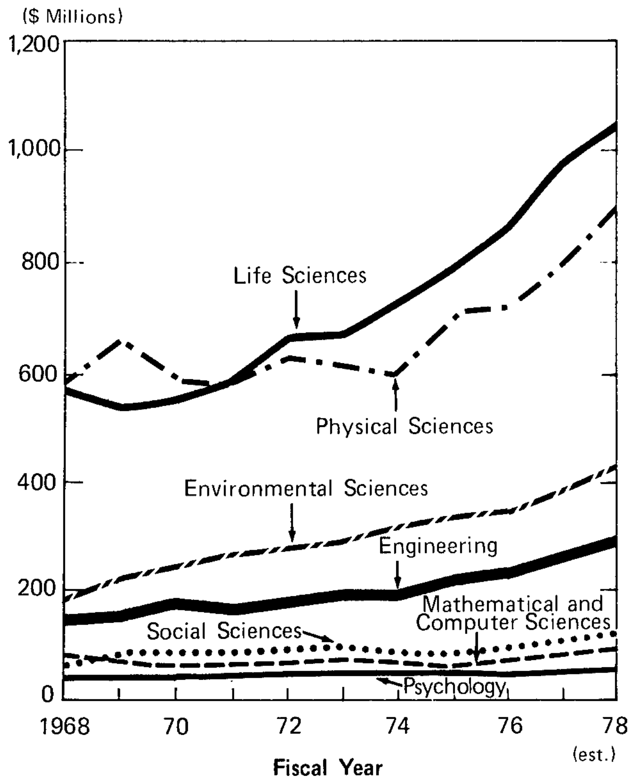
Field of science	*1968 actual*	*1977 (est.)*	*Percent increase or decrease*	*1978*
Total	$1,721	$2,755	60.1	$3,012
Life sciences	579	1,007	73.9	1,058
Psychology	55	53	(3.6)	57
Physical sciences	599	806	34.6	911
Astronomy	110	180	63.6	220
Chemistry	119	203	70.6	222
Physics	352	416	18.2	460
Other	18	8	—	9
Environmental	199	394	98.0	438
Atmospheric	107	128	19.6	132
Geological	51	155	203.9	184
Oceanography	40	100	150.0	110
Other	1	10	—	12
Mathematics and computer sciences	67	79	17.9	88
Engineering	156	268	71.8	297
Social sciences	61	102	67.2	113
Other sciences	4	46	—	49

Source: Division of Science Resources Studies/STIA/NSF

[2]See Appendix H.

[3]See Appendix I.

Figure 4.1—Federal obligations for basic research, by field of science, FY 1968-78



SOURCE: Division of Science Resources Studies/STIA/National Science Foundation.

Environmental Sciences

The environmental sciences received an estimated $394 million in basic research support in FY 1977, or 14 percent of all Federal basic research obligations. Four agencies provided 93 percent of the total support: NSF, $139 million (35 percent); Interior, $100 million (25 percent); NASA, $67 million (17 percent); and DOD, $64 million (16 percent).

Engineering

Federal agency support for basic research in engineering totaled $268 million in FY 1977. Four agencies provided 91 percent of this total: DOD, $82 million (31 percent); NSF, $68 million (25 percent); ERDA, $58 million (22 percent); and NASA, $37 million (14 percent).

Others

All the other fields of science accounted for $280 million, or 10 percent of total Federal obligations for basic research in FY 1977. Psychology, with $53 million, received its principal support from HEW, DOD, and NSF. Mathematics and computer sciences, totaling $79 million, were supported primarily by NSF, DOD, and ERDA. Five agencies provided 10 percent or more each of the $102 million total for support of basic research in the social sciences: NSF, HEW, Agriculture, Smithsonian, and Justice.

In addition to the traditional fields of science, other breakdowns can be used to analyze federally supported research. The NSF Division of Science Resources Studies has developed functional categories for analysis of R&D obligations by broad program areas to show priorities. These have not been broken down, however, into basic research, applied research, and development for the various functions. The functional category "Science and Technology Base" is mainly basic research; the remaining elements of basic research in the Federal R&D budget are scattered throughout the other functional categories. As noted in Appendix J, the 1977 estimated total for "Science and Technology Base" is $953 million, which is just 35 percent of all Federal obligations for basic research—$2,755 million in 1977.

CHAPTER 5

MANAGEMENT OF BASIC RESEARCH IN THE MISSION AGENCIES

Missions and Objectives

Part I contains agency interpretations of their stated missions. These are generally derived from their enabling legislation, from appropriations, and from other legislation. New laws frequently necessitate some reorientation of the agencies' programs, requiring them to review their objectives to insure these remain relevant to their missions.

The agencies show a striking similarity in their research objectives. In general, they formulate and support basic research that will enable them to accomplish their missions more effectively. The National Institute of Education (NIE), for example, is concerned with finding ways to develop new policy initiatives that will aid in understanding the learning process. The Department of Labor supports research exploring the interactions of people and their behavior patterns in personal and group negotiations. The National Aeronautics and Space Administration (NASA) conducts basic research that supports its mission or expands knowledge in fields of science relevant to its mission. The reliance of the military services on improved weaponry has made them conscious of the need for fundamental scientific studies. The Office of Naval Research (ONR) has a statutory responsibility "to plan, foster, and encourage scientific research in recognition of its paramount importance as related to the maintenance of future naval power and the preservation of national security."[1] To improve its services, the National Oceanic and Atmospheric Administration (NOAA) aims at research that will increase the general understanding of atmospheric and oceanic processes. The U.S. Geological Survey and the Office of Water Research and Technology (OWRT) conduct research in geology as part of their mission responsibilities for resources.

Organization

While each agency's organizational pattern of support for basic research is different, each generally employs key people who have responsibility for research program management. The senior research director or manager assumes overall responsibility. Middle managers are concerned with several programs in a selected general area. Subject area managers or program directors are responsible for reviewing project proposals in their particular fields. Staff members and reviewers evaluate proposals, and consultants analyze trends, suggest thrust areas, and review programs. In addition, each agency has budget, grant, and contract officers. Perusal of the agencies' own reports in Part I indicates that job responsibilities are similar; they vary primarily in the degree of authority granted the different officials. The organization of authority and the basic scientific management capabilities of the managers are the major determinants of program quality.

The Decisionmaking Process

Selection of what basic research projects will be carried out by agency staff in their own laboratories or by scientists in outside laboratories begins with a research plan, prepared on the basis of the agency's overall mission requirements. The plan is the result of an annual long-range planning process during which program suggestions are solicited from all levels in the organization. The suggestions generally are in the form of studies, which are sorted, selected, consolidated, and then circulated to all concerned staff for comment. The plan serves as a basis for preparing budgets and as a guide for program implementation when funds have been appropriated.

Mechanisms for Initiation and Termination of Basic Research Projects

The specific missions of individual agencies affect the types of plans and the mechanisms they use in planning. Agencies derive their research programs from past plans, from suggestions arising out of related research, from staff doing similar research, and from past proposals. Because in most agencies clear directives for basic research are not stated separately as a primary responsibility, such plans often are incorporated in general research plans. Basic research plans, therefore, can be expected to relate to overall R&D activities. When problems arise in an agency's R&D activities, one of the reasons may be the lack of basic knowledge.

The selection of research topics from those outlined in the general plan depends largely on the

[1]Public Law 588, 79th Congress (1946).

priorities accorded the completion of certain developmental or applied work needed to meet long-range goals. In selecting the amount of basic research to include, some agencies (e.g., NIE, Agriculture, and the Energy Research and Development Administration (ERDA)) try to allocate a certain percentage of their total research funds (from 6 percent up) to the basic areas—the amounts being subject to staff discussion.

In NSF and the National Institutes of Health (NIH), where support of basic research is a primary agency mission, the selection of research is a complex process. NSF initiates its planning in accordance with policies set by the National Science Board. The program managers assess the needs and opportunities in each of their subject areas. They base their recommendations to management on ideas received from professional societies and academies, discussions by program panels, contacts with the multitude of scientists they meet, and, often, on the commentaries received from *ad hoc* reviewers. This procedure encourages coordination with the programs of other research-supporting Federal agencies, such as NIH, where the program directors and the reviewers can see parallel proposals.

The Department of Defense (DOD) services, which support much basic research, also select research projects related to their mission requirements. In the Army program, the staff prepares for its laboratories a user-oriented document called the Science & Technology Objectives Guide (STOG), which specifies certain scientific objectives to guide the selection of research projects. The guide describes these objectives and relates them to future military operations, points out deficiencies, states objectives for future R&D activities, and indicates laboratories within the Army structure that are expected to undertake and support these activities. Laboratory directors as well as staff scientists review the documents, delineate the work they feel can be carried out, and propose to their superiors which projects should be budgeted. In the Air Force research program, each laboratory prepares planning documents for its projects, specifying budget, personnel, and equipment requirements. Those that involve basic research are channeled through the Air Force Office of Scientific Research (AFOSR), where they are examined for their relationship to the total basic research effort of the service and where selection takes place. Some high-risk programs are allowed in selected research activities, especially if the proposer has demonstrated a high potential for success.

NASA uses a management system for research called RTOP—Research and Technology Objectives and Plans. Under this system, a statement of objectives and plans is drawn up with an outline of all of the resources required. From this statement laboratories outline proposed research projects that are intended to meet the objectives. When the project is approved by headquarters, the action becomes a "contract" with the suboffices or laboratories that will carry out the research. Responsibility for directing the project is lodged with the individual laboratory and project directors.

With an approved research plan in hand, the next step in the research initiation process is to select the best and most appropriate performers. If the work is to be done in-house, the researchers' time and requirements and the necessary funding must be determined before authorization to proceed is given. If the locale has not been determined previously, the plan must be brought to the attention of possible performers, either by circulating a Request for Proposal based on stated agency research requirements or through personal contact between agency research managers and the community of interested researchers, or both, in order to encourage appropriate proposals.

Most agencies cite certain criteria as important in their decisions to support or not support research. Among these are the qualifications and competence of the investigators, the soundness of the project, the importance of the proposed work as described to the agency, the availability of facilities to the investigator, and funds needed to support the work. These criteria generally apply no matter how the plan is prepared—whether the research idea is generated by agency laboratory research personnel or by a proposer outside the agency. Some agencies report additional factors that influence final selection. The Air Force, Army, and Navy, for example, seek to maintain a balance of about 30 percent of their research in-house and 70 percent out-of-house. The military services also frequently find that specific research results are urgently needed and, under such circumstances, this factor influences their considerations. NASA and the military services also consider it desirable to have strong university, research institute, or industrial capabilities that are knowledgeable about agency programs and problems and that can be summoned in times of need.

Most agencies designate staff or outside reviewers to evaluate proposals. Often, the resulting recommendations are further examined by staff members, a committee, and/or a panel before the formal approval mechanism begins.[2] Agencies generally follow one of four methods to obtain advice:

[2]The reader is referred to Part I of this report for the agencies' own statements on organization.

- A single review by a panel, which passes the summary evaluation of the proposal to the program manager, who considers the advice and recommends action;
- A dual review system in which more than one panel evaluates the proposal sequentially (as in the NIH system, where the Study Section first ranks the proposals and an Advisory Council reviews these ratings and approves or declines the proposal on the basis of its relevance to the agency's plan);
- Mail review, whereby the proposal is mailed to reviewers who are experts in particular fields and a program manager then recommends action based on the review; and
- Program manager review, whereby the program manager has total responsibility for seeking advice (often obtained through personal contact with experts) and making the final decision.[3]

In special cases, when dealing with difficult or controversial decisions, some agencies may use several of these methods. There is a wide divergence of opinion among agencies and program managers on the relative value of the above procedures; the decision to adopt one or another is often based on customs in a field of learning as well as on agency programs and management patterns.

Decisions to terminate basic research programs are based on the same data and analysis as decisions on project renewals or extensions. Because progress in applied research usually depends on advances in basic research, agencies often evaluate the two at the same time. Almost every agency has adopted evaluation techniques, using one or a combination of visiting committees, panels, and consultants to assist management in deciding on project continuation. The National Bureau of Standards (NBS) uses four principal means for evaluating its research programs: (1) internal management reviews at each level in the Bureau; (2) a contract with the National Academy of Sciences to provide independent review and evaluation (29 panels are involved); (3) Bureau survey and evaluation by its statutory visiting committee; and (4) comprehensive analyses of issues in selected programs by qualified contractor personnel. (A more detailed description of this procedure is included in the NBS material in Part I.)

ONR relies on continuing site visits by the program managers and representatives from regional offices; NASA uses an annual review system that includes extensive detailed reports; NSF uses site visits and reviews of proposals for continuing support, together with such panel evaluations as may be available. For its national facilities, NSF requires that the contractor's governing board examine all programs and activities on a regular schedule, using such advisory or review committees as may be appropriate. These appraisals are reported to NSF on a schedule corresponding to the presentations of plans, programs, and budgets for subsequent years. In addition, the Director of NSF has established a program evaluation staff, which, through outside contract or by other assistance such as special consultants or *ad hoc* panels, seeks to evaluate entire programs. The National Science Board also performs a major role in the evaluation and approval of ongoing programs.

Regardless of what operational mechanisms an agency chooses for evaluating ongoing projects, the result is a determination that the work either should continue or be terminated. If the review suggests that the work probably will not yield results within a time frame the agency can accept (as is often the case when basic research is initiated to support some applied project), a panel often will recommend termination. Such recommendations generally pass through several layers of management. An examination of agency practices indicates that such terminations are more likely to occur when program funds are limited. Sometimes a project is selected for termination because such action is the only way to initiate fresher programs. Other reasons for termination include lack of qualified personnel and pressure to eliminate programs with long-term payoffs. By various means, then, agencies continuously examine and evaluate their new and ongoing basic research projects, continuing or terminating them in accordance with their mission objectives.

Criteria for Determining Levels of Funding and Sites Where Research Is Done

The agency-approved research plan influences the level of funding given a project and the selection of the laboratory or site at which it will be carried out. In selecting the material to be included in the plan, some bias is established which cannot be overlooked when the plan is carried out.

Decisions on levels of funding are influenced by several criteria, including: (1) the availability of funds in optimum or at least adequate amounts to support a reasonable level of research; (2) the probability that the general program or project will be successful; (3) the currentness of the research as determined by the literature and by pro-

[3]For a detailed discussion of review procedures, the reader is referred to Wirt, John G., Lieberman, Arnold J., and Levien, Roger E., *R&D Management: Methods Used by Federal Agencies* (The Rand Corporation: Santa Monica, Calif.), 1974.

posals being received; (4) the urgency of the results; (5) the relation of the research to the overall agency mission; and (6) the availability of qualified manpower. The availability of funds is the most important of the six criteria.

Choices are made first among the program areas. These are generally proposed during the overall planning process by program staff as the budget plan is formulated, then adjudicated by senior administrators, and finally adjusted and allocated according to the availability of funds. Once the decision on program areas has been made, the selection of individual projects is handled by program managers based on agency policies and regulations established according to the above six criteria.

To insure that basic research is not overlooked in their programs, several agencies allocate a percentage of available funds for the support of basic research. NIE, for example, allocates about 20 percent of its funds for basic research; ERDA has set its goal at 6 percent. Agriculture states its goal in other terms, allocating 5 percent of its research funds for the support of new ideas. (See Part I, Agriculture, for more detail.) Other agencies clearly use some form of strategy to support basic research but do not indicate precise numbers in advance of their project decisions.

The criteria applied and procedures followed in determining levels of funding for programs and individual projects in in-house laboratories are essentially the same as those applied to work under grant or contract. Most agencies approve projects or obligate funds only for the first phase of a research effort, intending to continue support, often at an increasing level, as long as the project shows progress. Such a procedure requires careful review and evaluation of the work in progress to insure that continued support is justified. Furthermore, this procedure permits program managers to support initiation of higher risk work, because they are assured scheduled opportunities to discontinue support.

There are numerous agencies—such as the Veterans Administration (VA), the Bureau of Mines, the U.S. Geological Survey, NBS, Smithsonian, and the Fish and Wildlife Service—whose research, except on rare occasions, is carried out solely by in-house laboratories. The VA supports no outside research. The work of agencies such as NBS, the Fish and Wildlife Service, and the U.S. Geological Survey, except for a few specialized programs, is done in their own laboratories. These agencies are not faced with a choice of location except in rare instances when the work is urgent and no in-house capability exists. Outside performers are then sought through a call for proposals.

Other agencies have no in-house laboratories and contract or grant funds for the designated research to a university or some research group or laboratory, an industrial performer, or, on occasion, to another agency laboratory. Such agencies include OWRT, the Department of Labor, the Agency for International Development (AID), NSF, the Advanced Research Projects Agency (ARPA, now DARPA), and the Department of Justice. In all these cases, the agencies seek to select the most capable performers through a review process.

Still other agencies have major in-house laboratories and contract laboratories that carry out a large portion of their research activities, but also support considerable extramural research in universities, research laboratories, and industry. These agencies include the Air Force, the Army, the Navy, ERDA, NIH, NASA, the Alcohol, Drug Abuse, and Mental Health Administration (ADAMHA), the Fish and Wildlife Service, and NOAA. Research management personnel decide during the various stages in the planning process where the research will be carried out. Because most planning procedures include input from working scientists, especially those in the agency's own laboratories, the site chosen is often the place where the scientist is already working, be it an in-house laboratory or one outside the agency.

Most of the agencies that have a choice of using in-house laboratories or contracting out first examine their own research capabilities before exploring those outside. The policy of some agencies, however, is to maintain both internal and external sources of research strength. The Air Force maintains a strong industrial capability that is considered to be on readiness alert in times of crisis. Although ERDA and NASA depend heavily on their contract laboratories (to which they give most of their support), both agencies maintain major programs in universities and industry, avoiding (as much as possible) any competition between their own laboratories and the universities.

Certain research requires the availability of specialized, costly facilities. Many of these are installed in Government or contract laboratories (e.g., Navy, Army, Air Force, NASA, ERDA, NOAA). The choice of site, therefore, is essentially limited to the laboratory with the appropriate equipment. Many of these laboratories with very specialized facilities make them available to qualified scientists regardless of their affiliation. These laboratories assign equipment, time, services, and available space in much the same way as agencies review proposals, calling upon reviewers and user group panels for guidance. Available facilities supported in full or in part by Federal

funds include ships (NOAA, Navy, NSF-supported university ships), telescopes (NSF), accelerators (ERDA, NSF), and wind tunnels (NASA), as well as many other specialized services and equipment. Some laboratories, such as the Joint Institute for Laboratory Astrophysics (JILA), are jointly supported by an agency and a university as a center for specialized studies.

ARPA, on occasions when it undertook very specialized research, needed particular types of laboratories (e.g., materials laboratories) and arranged for their establishment on university campuses. In keeping with ARPA's policy, support was discontinued once the special purpose was fulfilled. NSF, however, noting that the results of ARPA's research in the materials laboratories added considerably to the total strength of the Nation's research effort, and to avoid losing these laboratories, undertook their support.

The selection of a laboratory to carry out agency research also involves considering whether the research environment will be conducive to work on the problems that will be undertaken. An academic atmosphere, for example, is preferred for many laboratories that will concentrate on basic research; a more industrial atmosphere may be desired for other research.

Agriculture, NOAA, and ERDA have established laboratories on or near university campuses to promote a vigorous atmosphere for research. In this way they can make their special equipment available to the university research staff, arrange special joint appointments, take advantage of the easy exchange of ideas inherent in the university research community, and find new research ideas for their own problems.

Fifty or more federally supported laboratories (FFRDC's and others) are available in this country as research centers for visiting scientists. They are managed by a variety of organizations; many are located on or near university campuses. Whether their mission is broad or specific, all operate to enhance the capabilities in the laboratories and provide suitable sites that agencies can select for their projects. (The reader is referred to Chapter 1 for examples of their programs and management.)

Establishment of Priorities

In most agencies, setting priorities begins with an analysis of the programs and activities of the divisions supporting research. Agency requirements derive from legal, congressional, and constituency pressures or from executive branch decisions on general national priorities. These priorities in most cases are based on general agency responsibilities and related R&D activities needed to meet agency objectives.

In the Department of Agriculture, for example, basic research needs are suggested by scientists in the State agricultural centers, regional research centers, cooperating university departments, and other research groups working in agricultural research who become aware of needs and problems through their applied work. These suggestions are then discussed on several coordinating planning levels, where the project area is considered in light of current agricultural problems. All suggestions are then ranked by senior staff in the Agricultural Research Service management and planning system. Other agencies (such as NASA, the Department of Transportation (DOT), and the Department of the Interior) determine which areas seem most likely to contribute to the current objectives of the agency, based on public demand and administrative requirements. From these possible choices, selected basic research projects are programed and given priority within the agency's activities. Similarly, the three services in DOD each review the urgency of their requirements as determined by military planning and policy discussions, convert these into field and operational requirements of the particular service, and then assign priorities in the R&D plan. The basic research needed to support this work is then programed and given priority within the limits of available personnel and funds. ONR depends on the program managers' familiarity with both the scientific and Navy operational needs in setting priorities in the basic areas. They also seek advice from the National Academy of Sciences. The Army bases its decisions on written guidelines that state certain scientific objectives to be considered in the selection of research projects.

In NIH, priorities are in a constant state of adjustment in the various institutes and in the agency's university-related basic research programs. Priority decisions in various fields are made by program directors, who feed this information into the administrative planning activities in each annual planning cycle. In ADAMHA, research priorities are established during the budgetary planning process that takes place at nearly every management level.

In all agencies, then, mission requirements determine priorities. Priorities are always subject to change, however, because of new program thrusts, scientific breakthroughs, or budget changes. Continued flexibility in establishing priorities is essential so that research efforts can be channeled into the areas currently most productive.

Factors Affecting the Quality of Basic Research Projects

Regardless of where the work is performed, the vision and leadership of the senior officials who plan and direct the research are among the most important factors affecting the quality of basic research projects. Among the most important characteristics necessary for effective leadership, the agencies cited the willingness and capacity of research directors to understand what researchers do; to recognize research ability; to select personnel who are creative, productive, and compatible; and to provide encouragement. The military services, together with agencies such as NASA, Agriculture, Interior, and ERDA, also emphasized the need for the research manager to recognize productive research results. To this end, effective communication must be developed between the performer of the research, the research director, and the staff. The Navy summarized this view by pointing to the need to create a research environment around the staff.

Another factor affecting the quality of basic research is a personnel system that insures a productive staff. Incentives of various kinds are required. The majority of agencies reported the need for pay scales comparable to those of non-government organizations, a fair retirement system that provides security, opportunities for promotion and personal improvement, and incentive awards. In addition, NIH, the Navy, and ERDA reported the need for a free-thinking atmosphere with opportunities to exchange ideas and with sufficient competition to encourage good results.

Several agencies (ONR, NOAA, ERDA, Agriculture, NIH, and NBS) point to the success of their programs that bring their research staff in contact with researchers from universities. At NBS, visitor programs bring together staff members and scholars for considerable periods of time. At Agriculture, arrangements are made for staff members to join one of the agency's agricultural research institutes at a university, where they can improve and develop research ideas in perhaps more hospitable surroundings.

A majority of the agencies agreed that adequate facilities, including space and scientific equipment, are essential to the efficient use of researchers' time. To this end, a continuing program of updating and replacing obsolete equipment is essential; the agencies agree that more funds are necessary for this purpose. Facilities such as libraries and other sources of information also encourage the staff, increase their output, and promote the exchange of ideas.

Agency commitment to basic research is expressed in many ways, e.g., funding, facilities, visionary leadership, personnel policies, and personal contact. No small part of this commitment is the need to establish a meaningful program role for the organization. When Congress established the Office of Naval Research (ONR), it approved a management style that for 30 years has promoted the advancement of science and insured that basic research was supported while the special needs of the Navy were met. The management of ONR has identified three program roles for the Navy: (1) funding basic research; (2) insuring payoff by selective encouragement of research in specially selected disciplines; and (3) insuring that research results are manifest in mission improvements and, wherever feasible, are made available for direct use by other agencies or civilian services.

The process by which projects are selected for support is itself the primary determinant of the quality of research. The criteria by which NIH reviews research proposals summarize the factors many agencies feel affect the quality of research. NIH selects its projects based on:

- The likelihood that the project, if successful, will contribute new knowledge to the particular research area;
- The soundness of the rationale for the approach to be used and the project methodology;
- The capability of the investigator, based upon prior training and research productivity, to carry through the project;
- The appropriateness of the period of performance planned for the project, and the projected budget; and
- The adequacy of environmental facilities and resources for the project.[4]

Impact of Security Classification

The agencies have few problems with security and secrecy. Only the Defense agencies, NOAA, ERDA, and NASA cite any problems at all, the latter three indicating they are bothered only occasionally when some information obtained may have a minor impact on security or may limit some of the activities they might otherwise undertake. The Navy points out that most basic research done under budget category 6.1 (research) is unclassified and is so treated. The Army and the Air Force have some problems transferring some types of information to other agencies, and free publication may be limited in certain areas.

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[4]Private communication from Dr. Ann Kaufman, NIH, to NSB staff.

The actual military applications of basic research results are long-term and without definition of use at present, so there are few problems. However, some projects may require that only cleared persons be involved because of the need for certain information obtained separately from the basic research itself.

When necessary, the system usually can cope with the security problem to make basic research results available. Such transfer of basic knowledge to other scientists in the applied or developmental areas both within and outside the agency is indeed possible. Agencies make sure that breakthrough ideas that develop from basic research are transferred as rapidly as possible so that other work can benefit.

Dissemination of Research Results

Deficiencies in the publication, distribution, and availability of research results often are cited as major impediments to the fullest utilization of the products of research. But the agencies indicate that the problems are not caused by barriers within their own organizations. Indeed, supported scientists are encouraged to publish their results in journals or as reports. Furthermore, many agencies (the Navy, for example) do not consider a contract fulfilled until the research has been written up and prepared for publication. The agencies point out that, with few exceptions, their basic research is unclassified and is therefore free of restraints on publication.

One deterrent to the dissemination of research results is the time lag until publication in the scientific journals. Another deterrent is publication charges (page charges) levied on authors of journal articles to offset rising publication costs. Until recently, many program managers voiced concern that funds for these charges were inadequate. Their concern has been dispelled somewhat by regulations recently established by OMB.[5]

The system of publishing and disseminating research results may be confusing to the layman, but scientists understand the system and generally benefit from the apparent competition. Where duplication of research is disclosed, the accuracy of others' work can be checked. Most important, however, is that most quality research is published in some journal.

The desire for increased availability of information has prompted many agencies to establish their own information systems to produce reports and abstract and index primary publications. NASA has established an extensive system to announce, catalog, publish, and disseminate (in paper form and microfiche) reports of NASA-supported research. The *Scientific Technical Aerospace Reports* (STAR), for example, is a collection of abstracts of reports on aerospace projects and similar projects in other agencies (abstracts on the latter are obtained from the Smithsonian Information Exchange). NASA also produces the *International Aerospace Abstracts,* which covers journal articles, conference proceedings, and books supported by NASA. DOD requires that all its research reports are sent to the Defense Documentation Center (DDC). Unclassified papers are also sent to the National Technical Information Service (NTIS) of the Department of Commerce, in accordance with a Government requirement. In this procedure each supporting agency pays the input costs and supplies the first set of publications. The large volume of information being produced today is in itself a barrier to dissemination, and agencies' efforts to make information available are costly. Agencies such as NASA, HEW, HUD, and DOD are aware of this problem, and some are taking steps they hope will help.

Scientists often point to a lack of funds necessary to use some of the modern information systems. Special libraries, abstracting systems, and indexing services generally require payment for their use and often are expensive. Training in the procedures to use the facilities efficiently is also necessary, and time to undertake these efforts and get to the user terminals can be inhibiting. Scientists often find that information can be obtained faster and more effectively by word of mouth, through meetings, or by telephone. The chronic lack of travel funds, however, which prevents staff scientists from attending meetings and conferences where some of the most current information is transferred, is a common complaint.

Use of Consortia in Management of Major Facilities

Agencies needing to establish research facilities may select (if this option is allowed in their legislation) the mode of a Government-operated inhouse laboratory, or they may select some form of contract laboratory that is most likely to produce the results they need. They may decide to arrange for a single university to contract and manage a laboratory according to specified terms. Where program advice and planning on a scale broader than one university is desired, they may turn to some form of advisory council, made up

[5]See Title 41—Public Contracts and Property Management, 1-15, 205-48, revised as of July 1, 1976.

of representatives from several universities, for the substantive program guidance of the laboratory. There has been some criticism of this mechanism, which limits council activities to program guidance, with the managers from the contracting university generally dominating the operation.

Since World War II, many such arrangements have been made, including those with the University of Chicago for the Argonne National Laboratory, the University of California at Berkeley for the Los Alamos Scientific Laboratory and the E. O. Lawrence Livermore Laboratory, and Cornell University for the National Astronomy and Ionosphere Center at Arecibo, Puerto Rico.

At the close of the war, recognizing the need for large, expensive, specialized facilities to be available to scientists from many universities and laboratories, a group of five scientists led by I. I. Rabi proposed the formation of a corporation to manage the Manhattan District Engineers' proposed facility at Brookhaven, Long Island. These scientists, with the consent of the command of the Manhattan District Engineers, chartered the Associated Universities, Incorporated (AUI), under the Board of Regents of the State of New York. Under this charter, 18 trustees were to be elected by the board from a slate made up of one scientist and one administrator proposed by each of nine sponsoring universities. Originally three but now six trustees-at-large also are elected to the board by its membership. The trustees elect the officers of the corporation, the president becoming a trustee ex-officio. The trustees, as the governing body of the corporation, are responsible for the overall management and direction of activities. They serve in their own right but have access to the sponsoring universities for advice in carrying out their responsibilities. This arrangement was so successful that it has been copied (with appropriate modification) in the management of similar activities.

In other consortia the membership generally consists of a group of universities, each an institutional member of the corporation with selected representatives on a governing board. The consortium assumes the responsibility for management with the individual university generally supplying guidance through its board representation. The board hires a president to look after consortium management responsibilities, selects the directors of the laboratories, and oversees the program management in accordance with their contract with the responsible Government agency.

Because newly formed consortia generally have few fiscal assets, agencies allow for direct charges in the contract and, in addition, negotiate a management fee or allowance, which covers the costs of the consortium's own management expenses plus some additional funds to permit the accumulation of a modest fiscal reserve for emergency expenses. Most consortia have established committees and user panels to obtain special program advice and to insure that staff and nonstaff scientific research personnel using the laboratory have fair access.

At first there was a tendency to create a new consortium for each new laboratory, but after a certain number had been created, it was found more practical to ask one already established to undertake additional management responsibility. AUI, for instance, undertook construction of the National Radio Astronomy Observatory (NRAO) at Greenbank, W. Va., and later lent its management capabilities to the center. It has since undertaken the construction of the Very Large Array (VLA) for radio astronomy in New Mexico with the NRAO staff undertaking essentially the day-to-day management of the construction.

Almost every combination of advisory arrangement has been used in the organization of these consortia, all with some success. Such arrangements help guarantee governing bodies that understand basic research and can call upon the most capable scientists to help plan and direct the programs in the laboratories; this is considered to be a valuable national asset.

Oceanographic Ship Operations

With the establishment of the Directorate for National and International Programs in the fall of 1969, NSF recognized the need to focus special attention on management problems arising from the support of costly research facilities. Management problems with the national laboratories had been dealt with through the assignment of management, program review, and evaluation to contractor organizations. In 1969, oceanographic ship operations and construction support were identified as prime candidates for improved management. The first step was to consolidate operational support, upkeep, and construction responsibilities into a single office in the directorate. This action could be considered responsive to the recommendations of the Commission on Marine Science, Engineering and Resources, published in *Our Nation and the Sea*.[6] During the same year, NSF was assigned responsibility for the major new effort in ocean sciences, termed the Interna-

[6]Report of the Commission on Marine Science, Engineering and Resources, *Our Nation and the Sea, A Plan for National Action* (GPO: Washington, January 1969).

tional Decade of Ocean Exploration (IDOE).[7] The Commission noted that:

> Marine Science has become "big science," and our efforts are limited by inadequate technology. The Nation is poorly organized to marshal the arrays of multiple ships, buoys, submersibles, special platforms, and aircraft, as well as the complex undersea facilities required for important oceanic investigations and experiments of a basic character.

And it recommended accordingly:

> . . .that a small group of institutions, including the present leaders in ocean research, be designated by the Federal Government as University-National Laboratories and be equipped to undertake major marine science tasks of a global or regional nature. The laboratories should be distributed geographically for the adequate coverage of all parts of the oceans and would be expected to commit their facilities to serve the needs of scientists affiliated with other institutions.

Although it may have seemed tempting to establish a whole new set of regional laboratories, NSF decided instead to consolidate its support and management of oceangoing facilities within the new Office for Oceanographic Facilities and Support (OFS) and to encourage the formation of the University-National Oceanographic Laboratory System (UNOLS) in the academic community, thus promoting the coordinated use of existing facilities. The development of IDOE not only doubled NSF's investment in ocean science research, but also added a new dimension in size and complexity to basic research in oceanography. Together with the new OFS/UNOLS management structure, IDOE helped achieve the critical mass of facilities, equipment, manpower, and funding which the Commission had correctly identified as essential to a new era of ocean studies.

Through the cooperative mechanism of UNOLS, the fleet of ships operated by the academic institutions became a functioning unit sometimes known as the "academic fleet." An executive office for UNOLS, supported jointly by NSF, ONR, and other Federal agencies, was created to give the enterprise appropriate management, including a single point of access to ship users from nonoperator institutions. This office also insured that a *post hoc* record of annual utilization of the fleet would be available which would permit an evaluation of planning efficiency and efforts to economize. Special facilities such as the submersible DSRV/Alvin have been identified as UNOLS national oceanographic facilities, and their use is reviewed by UNOLS committees.

The Navy operates several oceanographic ships for its own programs, as does NOAA. The programs and operations of these ships are made available to scientists from other institutions as scheduling allows. Because many Navy oceanographic projects in universities utilize the university oceanographic fleet, ONR contributes to the cost of their operations.

In conjunction with UNOLS and ONR, NSF conducts an assessment of the material condition of the fleet, using the information to plan necessary support for upgrading the ships and to do long-range planning for fleet replacements.

By improving the management practices of these facilities, NSF and UNOLS have achieved a cost-effective and scientifically productive alternative to the development of national oceanographic laboratories proposed by the Commission nearly a decade ago.

Relative Merits of Contracts and Grants for Support of Basic Research

The two legal instruments used for extramural support of basic research are the contract and the grant. The procurement contract requires that both the agency and recipient follow the Government procurement procedures and regulations required by legislation and administrative order. Generally, the grant has been accepted as a simple way to make funds available while placing the responsibility for performance on the recipient.

These two award procedures at first represented "extremes," but because both have been modified over the years, they have become more and more alike. While it is often assumed that the grant is the simpler, less involved, and more appropriate instrument by which to award funds for the support of basic research, in many cases it has been made more restrictive by additional requirements. Conversely, a research contract for the "purchase" of research has, in some cases, been simplified, so that it has become easier to carry out basic research under the contract procedure than through grants (e.g., ONR).

The simple basic research grant has acquired more involved management procedures because agencies have felt it necessary to retain much of the decisionmaking authority in order to meet congressional and administrative concerns for accountability. Requirements related to procure-

[7]Letter from the Vice President (as Chairman of the National Council on Marine Resources and Engineering Development) to William D. McElroy, Director, NSF, November 7, 1969.

Table 5.1—Program management alternatives

	PROCUREMENT CONTRACT	*ASSISTANCE CONTRACT*	*COOPERATIVE AGREEMENT*	*GRANT*
FEDERAL ROLE	1. "Purchaser"	2. "Manager" of some assistance relationships	3. "Partner" or "Active Supporter"	4. "Patron" or "Passive Supporter"
PRIMARY RESPONSIBILITY	Federal	Federal	Shared	Recipient
TYPE OF FEDERAL INVOLVEMENT	Whatever involvement is necessary consistent with Federal Procurement regulations	Whatever involvement is necessary	Substantial management or technical involvement during performance on specific decisions, subawards, provision of guidance or technical assistance,or collaboration	Federal delegation or development of decisions and approvals
RIGHT TO REDIRECT OR CHANGE WITHIN SCOPE	Unilateral Federal right to change or direct	Unilateral Federal right to change or direct	Recipient right to change or redirect, subject to Federal advice, assistance, persuasion, or concurrence	Recipient right to change or redirect

Source: Newton, Robert D., "Program Management Alternatives — Contracting Under Grants: The Need to Define the Federal Role," *Public Contract Law Journal, 9* (1977), pp. 35-49.

ment of materials and services have been added to grants, and detailed controls are included to insure compliance with administrative regulations on civil rights, fair labor practices, equal opportunity, and other areas, all of which have added to the complexity of grant administration. The grant thereby has ceased to be a simple support document making funds available for research. It has taken on the complexity of a contract, so that in many ways the two are almost indistinguishable.

The requirements for accountability for the expenditure of Federal funds and compliance with other laws and regulations are the major causes of the increase in paperwork on the part of agencies and recipients of grants and contracts. State and local governments, State universities, and the major independent universities complain about the increasing "intervention" of the Federal Government in their research grants. Indeed, the President of Harvard University recently said:

> The rising tide of government intervention has begun to provoke serious concern from many colleges and universities. . . . In a few short years, universities have been encumbered with a formidable body of regulations, some of which seem unnecessary and most of which cause confusion, administrative expense, and red tape. If this process continues, higher education will almost certainly lose some of the independence, the flexibility, and the diversity that have helped it to flourish in the past.[8]

Two separate attempts are now being made to deal with this problem. OMB Circulars A-101, A-102, and A-110 were developed to simplify and standardize Federal requirements imposed on grantees.[9] Federal agencies are now in the process of implementing these requirements.[10]

Legislation also is pending which would have the effect of reestablishing the integrity of the traditional grant—the Federal Government would again become a passive supporter or patron of the project.[11] The procurement contract would be used when the Government is the outright purchaser of research services. In addition, two new categories would be established, the "assistance contract" and the "cooperative agreement." Under the assistance contract, the Government would have in certain situations the rights established in a Federal procurement contract, especially the unilateral right to change or redirect the work if deemed necessary. The cooperative agreement would be an arrangement somewhere in between the assistance contract and the grant: the Government would be a partner and active supporter of the research, sharing the responsibility with the grantee for certain problems, including involvement in specific decisions and subawards during the performance period. With this new category of award available, the grant could be reestablished or reemphasized as the award that would return to the awardee the right to redirect or change the program when necessary.

Many believe that clarifying the various research relationships would reduce the confusion in the community. Table 5.1 summarizes these management alternatives, indicating the roles that the Federal agency and the award recipient would bear.

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[8]Derek Bok, Harvard University, The President's Report, 1974-1975, delivered January 10, 1976, pp. 4 and 22-23.

[9]Now being incorporated in Federal Management Circular (FMC) 73-8.

[10]NSF has implemented these circulars in its new Grant Policy Manual, *Federal Register*, July 29, 1977, Part IV, p. 38746.

[11]Federal Grant and Cooperative Agreement Act of 1977 (S.431 and H.R. 7691). This act was passed by Congress on January 19, 1978, and signed by the President on February 3, 1978, as Public Law 95-224.

CHAPTER 6

EFFECTS OF RECENT LEGISLATION ON AGENCY SUPPORT OF BASIC RESEARCH

Introduction

To generate the material for this chapter each Federal agency was asked, "What legislation in the past 8 to 10 years has had a significant impact on your agency's support of basic research?"

Some agencies listed recent enabling legislation that defines their missions, with no comment about its impact on basic research. Others listed general legislation not directly related to their own missions. Others indicated that the question did not apply to them because no substantial changes in their statutory authorities or responsibilities had occurred recently. (Some agency responses contained in Part I include comments on significant recent legislation affecting the agency mission.)

Frequently the acts and legislation cited by agencies are not specifically related to their basic research. Respondents most often identified legislation that had a significant impact on all research and development activities and did not confine their comments to their basic research activities. This is easily understandable in view of the lack of sharp distinction between development, applied, and basic research and the frequent intermingling of these activities.

General Legislation

In the past decade a number of Federal statutes have been enacted that affect all sectors of society, including institutions that conduct basic research—Government agencies, universities, industry, and nonprofit research organizations. Some statutes can be classified as general legislation that was passed in response to concerns for the welfare of the Nation and that may have affected basic research only incidentally. Nevertheless, some agencies point to them as having impact. In some cases the impact is regarded as positive, in others as inhibiting.

Civil Rights

One such "general" act is the Civil Rights Act of 1964, as amended, and the related implementing affirmative action requirements for employment of minorities and women. Nonfederal organizations or activities supported by Federal funds that are found in noncompliance become ineligible to continue receiving Federal funds. In recent years, a number of universities and other research organizations have been held in noncompliance and threatened with the withholding of all Federal funds. To be in compliance, the universities or research organizations must employ an adequate number of minorities and women. They must adjust salaries so that each employee is given equal pay for the same work or position. These requirements often call for significant changes in the structure of the whole institution and are not confined to those activities that are directly federally funded, such as research or student aid. Moreover, the requirements accompanying one small grant or contract can have the same institutional effect on a university as a high level of Federal funding.

Implementing this law, then, has imposed substantial costs on the most active research universities because of necessary salary adjustments, new employment requirements, and increased record keeping and reporting, all of which require additional bureaucratic structure. For universities that are under heavy financial stress, these costs are a severe burden and adversely affect the support services available for research, according to agency reports.

Environment and Protection of Life

Another set of enactments with nationwide impact deals with the environment and protection of life. The particular measures cited by the agencies include the Water Pollution Control Act, the Coastal Zone Management Act, the National Environmental Policy Act of 1969, the Clean Air Act of 1976, the Endangered Species Act of 1973, the Marine Mammal Protection Act, and the Occupational Safety and Health Act. In some cases, it is claimed, the cost of doing the same research is increased as performers comply with these laws. The laws require changes in many research operations—such as remodeling laboratories or modifying practices affecting by-products or waste. These remodeling and facility costs amount to many millions of dollars and will adversely affect research funding if budgets are not increased. On the other hand, environmental legislation may have positive effects on basic research. Creation

of the Environmental Protection Agency (EPA), for example, and the acts related to its mission, have stimulated a variety of new programs involving basic research. Similarly, agencies such as NSF and the National Institutes of Health (NIH) have increased their research on ecological and epidemiological questions, undoubtedly stimulated by the national concern about environmental conditions.

Specific Legislation

In addition to general legislation, several agency respondents report that other acts have had an impact on specific types of research. These acts affect the use of experimental animals and human subjects, the protection of privacy, research on the human fetus, and the use of dangerous drugs (as regulated under the Controlled Substances Act of 1970), and generate concerns about the free conduct of research. They are discussed in detail, along with other barriers to research, in Chapter 7.

Some agencies mention legislation and other congressional actions that limit their operations or prohibit them from conducting certain work. The House Appropriations Committee Report (No. 94-517) on 1976 Department of Defense (DOD) appropriations limits military medical investigations to "military unique medical problems." The action specifically limits drug abuse and venereal disease research, previously conducted in DOD, to HEW. Likewise, the Controlled Substances Act requires the Secretary of HEW to review and approve all drug-oriented research. DOD claims that these limitations hamper some military medical projects.

The Mansfield amendment to the DOD Appropriation Act of 1970 (P.L. 92-121, November 1, 1969) required a "direct and apparent relationship" between DOD-funded research and DOD's mission. This legislation created barriers to research both in and beyond DOD. The Mansfield amendment as a barrier to the conduct of basic research is discussed more fully in Chapter 7; it is also mentioned in Chapter 3.

Legislative Authorization and Funding

Several agencies, including the U.S. Geological Survey and the National Bureau of Standards (NBS), point out that funding for research has not kept pace with the increased responsibilities derived from their enabling legislation. The agencies affected accept the increased responsibilities but say they do not have the means to fulfill them. All the agencies feel they could be more productive if more funds, more positions, and more facilities were provided.

Legislation having a major impact on NIH in the last 8 years, beginning with the Family Planning Services and Population Research Act of 1970, has created institutes concerned with categorical diseases—requiring research on cancer, heart, lung, and blood diseases, multiple sclerosis, diabetes, arthritis, digestive diseases, and aging. NIH staff point out that this greatly widened mandate for new research initiatives will undoubtedly have an impact on research, but they also express apprehension that adequate funds will not accompany the new responsibilities. This has not been the case in funding for the National Cancer Institute but possibly will be so in funding some of the other initiatives. Support for basic research in categorical institutes is influenced by many elements; therefore, the long-term impact of such legislation on basic research is difficult to predict.

The National Aeronautics and Space Administration (NASA) observes that environmental statutes and pollution controls have little or no effect on the basic research it supports—but do have a significant impact on highly directed or applied R&D projects. Probably this observation applies to most legislation listed above. Applied research—by its nature and because it may involve pilot projects, test or model programs, and other actual applications—has a much greater potential impact on the environment than does most basic research.

The Agency Role

Agencies normally play an active role in developing legislative authorizations and statutes that affect their missions; they often work closely with Congress and the Office of Management and Budget (OMB) in originating the acts. If the legislation is proposed by the executive branch of Government, the agencies may initiate and even be entirely responsible for drafting the bills. If the initiative is in Congress, the agencies will work with legislative staffs and participate in hearings; both activities provide opportunities for agency initiatives and for amendments to be drafted. The complex interplay between agencies and Congress allows for adjustments to meet the agency requirements. Congress is usually sympathetic to agency needs once the needs are fully understood. In recent decades the research-intensive

agencies have experienced repeated expansions of their mission objectives and appropriations, although they may not have enough funds, positions, or facilities to do all they would like. Examples are the categorical expansions in NIH, the recent creation of the Department of Energy, and the earlier formation of EPA and NOAA. This expansion has had a significant impact on federally funded and conducted basic research as well as on applied research. Several respondents observe that, relative to the total R&D budget, basic research has been unintentionally but proportionately diminished as the missions of these agencies have expanded.

CHAPTER 7

BARRIERS TO OPTIMUM SUPPORT AND CONDUCT OF BASIC RESEARCH BY THE MISSION AGENCIES

Three questions asked of the agencies relate closely to the subject of this chapter. They are:

- What barriers exist to optimum support of basic research by your agency?
- What changes in Federal regulations and policies would facilitate conduct or support of basic research by your agency?
- What Federal regulations and policies, if any, impede the conduct and/or support of basic research by your agency?

The capacity and eagerness of U.S. scientists to conduct basic research seem to be almost unlimited. The constraints, however, are numerous. Limited funds, facilities, and manpower, plus the imposition of controls from outside the agencies, are cited as barriers to the possible achievement of a more desirable level of basic research activity. The optimum goal of the mission agencies is to contribute to scientific knowledge and to promote research results that will be useful in solving every problem facing the agency as it carries out its legislated purpose. As long as problems exist and faith that knowledge will bring solutions persists, the agencies, if given a free hand, would support more research. Incidentally, it is not clear how great an increase is desired in basic research compared with applied investigation. The Air Force responds that the achievement of "objectives" is the primary motivation—and applied work is probably the most common approach.

One response gives a summary of the attitude expressed by many agencies:

> The optimum situation for Air Force research would be enough good scientists working on every identified problem to reasonably assure its solution. Lack of resources forces the program to focus on certain higher priority problems and ignore others. For instance, of 489 research objectives identified by Air Force Systems Command, the Air Force Research Plan identified work on only 297 or 61 percent in fiscal 1978.

The overall control of agency activity in basic or applied research is exerted by external decisions manifested in legislation, appropriations, and executive and agency administrative judgments. In spite of this, the agencies generally express satisfaction with the system. They want to do more research, but they want other things, too. The balance within and between agencies and the operation of the Federal "system" of research is one they understand and support. They did not respond with alarm or a sense of desperation but rather as people working within a system they have always tried to improve. Nevertheless, the specific barriers they mentioned and the recommendations for improvement they offered are numerous and important.

Funding

Limited funding for basic research is viewed as a primary barrier. Obviously more funds would allow more research. The emphasis in the responses, however, is not so much on funds as on fluctuations and uncertainty in how the funding is provided. As was mentioned in the responses from the research community to the National Science Board, and described in the Eighth Board Report,[1] funding stability is regarded as highly important in basic research.

The response from the National Institutes of Health (NIH) on unpredictability in funding deserves quotation:

> Unpredictability in funding probably tops the list. This issue is not unique either to NIH or to basic research, but is nonetheless significant. The model of the lone scientist working by himself with equipment put together with rubber bands and paper clips is no longer valid, if it ever was. Biomedical science today requires a range of technical support services, complex equipment, often collaboration between a number of scientists and frequently a great deal of time. All of this is expensive. Under these circumstances, uncertainties and interruptions in funding can make it extremely difficult to keep research teams together for the length of time required to complete work on any given problem, or to fully exploit existing leads, with the result that the efficiency of the enterprise is markedly reduced. Any activity which is subjected to a series of arbitrary, externally induced stops and starts is bound to suffer. Basic research, a difficult, often frustrating, long-term endeavor is particularly sensitive to such disturbances.

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[1] *Science at the Bicentennial: A Report From the Research Community*, report of the National Science Board/1976 (GPO: Washington, 1976).

Along the same lines, the response from the U.S. Geological Survey (USGS) expresses the need for multiyear funding but also advocates flexibility in the distribution of funds, a point made by many other agencies:

> There are two primary regulation and policy changes that could have a substantial positive effect on research activities. First is the expansion of the availability of multiyear funding. Year-by-year funding is inconsistent with the basic research, which is often a multiyear effort. Second is the method by which funds and positions are appropriated and allocated. More flexibility should be given to laboratory directors to distribute and redistribute research funds and personnel among competing areas of research. Concomitantly, laboratory directors should be held more accountable for their performance.

Several other agencies feel that less restriction on the limitation of funds by research category would be helpful. Some (such as the Air Force) assign a specific percentage of funds available to in-house work. Others make specific allowances to applied or basic work. Generally, however, they feel that agency science administrators and laboratory directors should have the freedom to be more flexible.

Position Control and Civil Service Regulations

Federal budget control is rigidly applied in the allocation of positions. In some instances, agencies have been granted appropriations to perform an operational mission, but because of position control, have not had adequate personnel to do their work. Other agencies observe that they have more missions and tasks than dollars or persons to do the required work. Manpower barriers cited include Civil Service requirements, personnel ceilings, average grade level restrictions, hiring freezes, and fixed salary levels. A greater problem—the special requirements of employing scientists—is one which has long been a concern of Federal science administrators with a larger manpower problem. The retention and motivation of scientists, especially in light of competition with universities and industry, is part of the problem. Salary levels are apparently not as difficult to deal with in career management as the constraints of the Civil Service regulations. As recently as 1970 a task force on Federal laboratories recommended a two-category system for senior Federal employees. One category would consist of executive positions in policymaking and major management responsibility and the other of professional specialists working on research requiring creative and innovative talents. The report emanating from the task group was never adopted.[2] However, some science managers point to a continuing need to be able to operate in a system outside of the regular Civil Service rules. The particular requirements of scientists employed by the Government should be recognized. Their recruitment, development, and promotion, and their need to transfer in and out of particular laboratories and to move freely between Government and universities, could be dealt with more effectively if added flexibility were provided for.

Personnel

In periods of science manpower shortages, research is automatically limited. Now, when scientists in some fields are readily available, position controls and manpower ceilings are major barriers for the agencies that want to operate more actively. Shortage of competent persons in certain fields is also a limiting situation.

The prediction of the general manpower supply of scientists is a perplexing task, but there is no question that available young scientists in many fields are not fully employed at present. With university enrollments becoming stable, or even declining in some sciences, available science faculty will exceed the number of university positions in some disciplines, e.g., the social sciences. Research grant funds available for young investigators are not increasing as proposals increase. It is believed by some that many young scientists are not being incorporated into the research system as was previously the case. Fear has been expressed both by agency respondents and by others that the country may be losing part of a generation in the normal stream of science manpower.[3]

"Red Tape"

Many agencies are concerned with the requirements for accountability reporting and with the effects of "red tape" on the operation of re-

[2]Report to Federal Council for Science and Technology dated November 2, 1970, prepared by the Committee on Federal Laboratories, chaired by Dr. Lewis M. Branscomb, and transmitted to Dr. Edward David Jr., Chairman of the Council, with additional review as contained in a letter from Dr. Branscomb to Dr. David dated December 30, 1970.

[3]*Science at the Bicentennial,* op. cit.

search. The response from ERDA is representative of the responses of the agencies:

> . . . it is generally true that there has been, in recent years, both internally and externally, a proliferation of bureaucratic procedures, requirements, uncertainties in organization and calls for ever increasing paperwork and studies—all of which have absorbed large proportions of the time of program administrators and laboratory and university investigators. Inefficiencies are one consequence. An even greater concern is the tendency of these demands to dispel creativity and vision.

The Navy response to the question about impending regulations covers a variety of details but also comments on the reporting regulations. It says:

> Any policy or regulation which restricts the way in which funds can be spent eventually impedes the conduct and/or support of research. The limitations from Congress which come under the general heading of Incremental Funding have in the last few years caused a certain amount of disruption. Although the Congressional requirements for Incremental Funding were considerably softer for 6.1 funds spent at universities, there was still an impact.
>
> This last year the restriction on the amount of money which can be spent at Navy laboratories has caused significant disruption in the research program. Certain laboratories have unique facilities and/or people with unique talents. The In-House/Out-House Ratio has had the effect of denying to the Navy, at least temporarily, access to the best people and facilities for doing certain research. The impact from the laboratories' points of view has been disruptive and demoralizing.
>
> Increasingly, the Armed Services Procurement Regulations (ASPR) impede the support of research. ASPR was not written with the objective of facilitating the support of research. More complaints are heard every day from university administrators and research scientists concerning the difficulties in meeting all of the requirements for doing research for the Defense Department.
>
> Questions of sole source procurement have become an impediment in the support of research.
>
> All of these issues tend to pale when compared with the impact that recent personnel policies may have on Naval Research. Restrictions on numbers and grades of scientific and technical personnel can eventually bring the total Navy research program to a state of applied mediocrity.

It may appear ironic to people outside the Federal bureaucracy that agency administrators are complaining about reporting, red tape, and Federal regulations. It should be remembered that, for the most part, the scientists in administrative and laboratory positions are seldom the originators of such regulations. They are required to respond to the Office of Management and Budget (OMB) and congressional requirements and they have the same feelings, in many cases, as people outside the Government. They complain but also say they understand why regulations are required.

Basic-Applied Research Classification and the Mansfield Amendment

Many agencies regard the increasing emphasis on applied research as the major barrier to the conduct of basic research. The pressure of today's problems and missions detracts from the optimum support of basic research. It is also stated that in a period of shrinking budgets basic research is downgraded in priority. In the National Aeronautics and Space Administration (NASA), basic research funding was reduced from $380 million in FY 1969 to $320 million in FY 1977. The ups and downs of basic research funding for agencies (see Introduction) must have a number of causes, but the applied mission priority is cited as one important cause.

The statistics, however, can be confusing due to different ways of classifying research. As the National Oceanic and Atmospheric Administration (NOAA) points out, its support of fundamental research on atmospheric processes and characteristics is reported as applied research because it relates to its mission in weather forecasting. On the other hand, when NSF supports the same research it is classified as basic. Also, the statistical classifications may be flexible in responding to the fashions and priorities of the time, so what one agency classifies as basic research another might define as applied.

In October 1974, the National Science Board adopted a resolution encouraging mission agencies "to maintain strong basic research programs in areas that have the potential of contributing to their mission objectives." This was done at a time following substantial Government budget reductions in support of basic research. In addition to budget reductions, many agencies had dropped laboratory support outside their own laboratories

and also work in certain disciplines. Thus, the Government's total basic research effort was reduced. Scores of programs were closed and responsibilities were transferred from some mission agencies to others, notably to the National Science Foundation (NSF). NSF had difficulty in deciding which programs dropped by other agencies should be supported, since it could not fund all programs.

The "drop out" sequence was initiated in the Department of Defense (DOD) because of the so-called "Mansfield amendment." The Navy description of the effect of this amendment follows:

> It is surely the case that Section 203 of the 1970 Military Procurement Authorization Act, the Mansfield Amendment, has had a significant impact on the Navy's support of research. The Mansfield Amendment changed the way the Navy *perceived* its research program, it changed the way university investigators *perceived* the Navy research program and it gave a title and focus to trends which had been underway in the Defense Department and in the government support of research.
>
> The Navy, the Office of Naval Research, has from the beginning been acutely aware of its role as a mission agency and of the necessity to support research in the interest of the Navy. The question of relevancy entered the earliest debates as the first research programs were being established in ONR. Over the years *the interpretation of relevancy tended to become narrower.* The Mansfield Amendment created an atmosphere where it was felt that the program, task by task, must be clearly relevant to the man-in-the-street. After Section 203 it was no longer sufficient that the programs' relation to the present or future Navy be clear to the scientists in the Navy and Defense Department; the relation had to be reasonably clear to those who chanced to look. With this kind of atmosphere it was naturally necessary to drop certain tasks.
>
> Perhaps more important was the effect the Mansfield Amendment had on Navy contractors and potential contractors. Researchers in the United States had been accustomed to bringing to the Office of Naval Research their very best ideas without prejudging the relevance issue. It was always understood that the issue of relevance was an issue to be decided by the ONR scientific officer and not the proposer. The Mansfield Amendment made researchers acutely aware of the relevance issue and caused them to prejudge the relevance of their work with the ultimate result that the Navy failed to receive proposals that normally would have come to ONR.
>
> The diversion of the flow of proposals away from the Navy and toward other agencies, mainly NSF, was surely accentuated by the Mansfield Amendment, but the trend had already begun. Indeed the growing expectations of the scientific community, the growth of NSF coupled with the relative decline of ONR's influence, the reactions against the war in Southeast Asia, all had the effect of inhibiting the flow of proposals to ONR. The Mansfield Amendment was in a sense a legal symbol for a trend already in force. It gave focus to the fact that the National Science Foundation had taken over a role that ONR no longer played.
>
> The end of the Draft had the interesting effect of providing an impetus for a broad based program in manpower research. Again, the trends were already in force. The end of the Draft signaled an increased urgency in attacking problems of recruitment, retention and all of the other military manpower issues in today's society.

Every agency science administrator is plagued by the mission relevance question, especially in relation to basic research. For example, to the Office of Naval Research (ONR), support of pure mathematics is highly relevant to the Navy mission but perhaps this would not be so regarded in some sectors. Similarly, NSF has been plagued since its inception by persons who ask how many of the supported projects can be justified and to what extent they relate to any conceivable national purpose. Scientists within the agencies feel that skepticism is due to a lack of understanding of what basic science is about and how it relates to the national purpose. The science administrator is caught between the scientist, who believes any scientific inquiry is justified, and skeptical citizens or Congressmen, who wonder how esoteric inquiries can warrant public fund support. As the pressure mounts, the research administrator finds applied research easier to justify than basic.

The relevance question, brought to the forefront in all Government agencies because of the Mansfield amendment, has effected a serious reduction in basic research support. However, a recovery is in progress, according to the statistics on Government support of basic research. It could be that quite solidly justifiable mission-applicable work, labeled "applied" in the statistics of an earlier time, is now classified as "basic," and vice versa. Because research support data reported by the agencies change in response to a number of

fashions, forces, and interpretations, uncertainty will continue about trends.

The response of NOAA, as indicated above, deals with the basic versus applied classification problem. It also deals with other administration problems in viewing barriers to optimum support. For example:

> The "optimum" level of support depends on the management level at which the optimizing is done. At the laboratory or research division, the allocation for basic research may appear quite inadequate but at higher levels this allocation may appear to be approximately optimum. It depends on the legal, policy, budgetary, and management constraints at the various levels. In addition to the constraints internal to the Federal Government, there are external constraints such as the number and quality of organizations competing for these researchers. The optimum level of support therefore depends on the constraints that are to be relaxed or changed.
>
> An additional variable, or constraint, here is the definition of *basic* research. NOAA support of research into fundamental atmospheric processes and characteristics can be called *applied* research because of NOAA's mission to improve weather forecasts. In some other agency, such as the National Science Foundation, the same research may be called basic research because it is considered to be an advancement of scientific knowledge.
>
> Within budget constraints on the long term, it is currently felt that NOAA has achieved a reasonable balance among basic research, applied research, and operations. On the short term, funding can be a barrier to support of special basic research programs that NOAA believes should be pursued. Availability of the required scientific capabilities can also be a barrier on the short term.

Research on Human Beings

Recently, research vitally affecting human beings and their condition has attracted attention. Legislation, regulations, hearings, and related actions have been generated by desires to control research using human subjects, including children, prisoners,[4] and patients. Similar attention has been given to the protection of privacy of persons involved in research and research on the human fetus. Just as the technology affecting abortion and conception has brought birth control and population questions to the level of intense public debate in Government, so too these other avenues of research stimulate debate regarding regulation.

The concern here is whether these laws or regulations have, in any way, become barriers or inhibited basic research. The most restrictive act (Section 213 of P. L. 93-348—The National Research Act, 1974) prohibited "research conducted or supported by the Department of Health, Education and Welfare (HEW) in the United States or abroad on a living human fetus, before or after the induced abortion of the fetus, unless such research is done for the purpose of assuring the survival of such fetus." The act called for a National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research. In the National Research Act creating the Commission, support of research on the fetus was prohibited for 4 months until the Commission reported its recommendations. The Commission's 1975 report recommends application of a number of restrictions on the conduct of such research.[5] The ethical issues considered by the Commission are perplexing and complex. While the restrictions on research apply only to federally funded work, these federally established ethics or regulations will undoubtedly apply to any work and inhibit a variety of previous practices. Much earlier, in 1966, the Public Health Service required and NIH issued regulations about the use of human subjects. These regulations were stimulated by a history of misuse in behavioral research on human subjects; this misuse also prompted the 1967 "Privacy and Behavioral Research" report of the Office of Science and Technology.[6] The regulations required that organizations conducting research using human subjects organize review boards designed to protect human subjects in all areas of research. It became mandatory that any projects involving human beings were not eligible for funding until approved by such boards. Now agencies other than HEW, such as NSF and ERDA, require similar review before funding such projects. A recent study conducted by the Survey Research Center at the University of Michigan for the National Commission reported that:

> The existing review process was viewed more favorably than unfavorably by most research investigators and review committee members.

[4] *Research Involving Prisoners*, report of the National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research (HEW: Washington, 1976).

[5] *Report and Recommendations—Research on the Fetus*, HEW Publication No. (OS) 76-127 (HEW: Washington, 1976).

[6] *Privacy and Behavioral Research*, a report of the Executive Office of the President, Office of Science and Technology, February 1967.

However, a substantial minority, particularly of the investigators, felt that the procedure is an unwarranted intrusion on the investigator's autonomy, that the committee gets into inappropriate areas, that it makes judgments it is not qualified to make, and that it has impeded research. The most frequently indicated problem (from a list of 10 problems) felt by board members was getting members together for meetings. Between a fourth and a third of the members indicated problems due to the need for rapid action in order to meet deadlines imposed by funding agencies, the lack of precise DHEW guidelines, and the time spent unnecessarily reviewing research with little risk.[7]

Thousands of proposals are examined by review boards, and the costs are borne by the institution. In some universities, the process provides for no appeal of committee decisions. The imposition by the review boards of research protocol objectionable to the investigators is also cited as impeding research and limiting the freedom of research. Some investigators allege they would rather do no research than submit to such review and regulation.

Congress has recently considered bills that would regulate research involving recombinant DNA; this was in response to pressure for such legislation initiated in the scientific community itself. Concern about the conduct of such research by industry or nongovernment-funded laboratories has raised fundamental science and society issues, such as the freedom of scientists to investigate whatever interests them and the extent of the Government's constitutional power to control scientific inquiry and the search for knowledge beyond decisions to control funding.

Present regulations controlling the use of human subjects, animals, and dangerous drugs or chemicals, plus the application of OSHA safety standards to research laboratories, may have substantial effects on the cost and complexity of conducting research, and, in some cases, may impede or prohibit the actual conduct of research even beyond the impact of increasing costs.

OMB Regulations

Agencies such as the Department of Housing and Urban Development (HUD) that support social science research find OMB regulations on the control, design, and use of survey questionnaires and protocol to be serious barriers to the conduct of effective research. HUD comments:

> These regulations, when taken together with the current government-wide drive to reduce paperwork burdens on the public and private industry, are so onerous as to be an effective barrier to the performance of many social-science research projects. Surveys of a properly drawn sample population are, in fact, among the most effective means of reducing paperwork burdens, when contrasted with typical government requests for information from an entire population.
>
> Yet surveys are being treated by OMB as though they are just another paperwork burden. Agency quotas have been imposed. No new survey may be undertaken unless an older one is discarded. Lengthy reviews are required of every question in every survey instrument aimed at ten or more respondents. The delay from these reviews can be disastrously expensive, if there is a contractor standing by waiting to perform.
>
> In view of OMB's procedures for survey review, HUD now uses a circuit-breaker clause in its contracts to cut off any contractor expenditure, when survey review time exceeds 60 days. This merely transfers the direct costs of delay from the government to the contractor. Ultimately the costs will be reflected in contractors' burden rates and partially or wholly come back to the government. It could also lead to a dropout of contractors from this field. None of this does the government, or the public it serves, any good.
>
> These two kinds of regulatory problems with OMB have a chilling effect on the conduct of social science research by a mission agency.

OMB regulations are considered by some agencies to be a barrier to research dealing with human behavior in another way. HUD's response includes the following comments:

> We sense a very strong reluctance on the part of OMB examiners to permit any research involving a control population, which does not receive a benefit given to the experimental population.
>
> For example, HUD and a nonprofit agency wished to test the hypothesis that job placements would be higher for inner-city unemployed persons receiving job counselling, if they were also given housing counselling at the same time. It was believed that job opportuni-

[7]Dated October 2, 1976, revised November 23, 1976.

ties in the suburbs were being passed up because the potential job applicants could not obtain suitable nearby housing, or were subject to overt or subtle discrimination.

A standard four-cell research design was prepared. Before and after measurements were to be made of an experimental group, which would be given both job and housing counselling. Before and after measures were also to be made of a control group, which would only receive the standard job counselling. Ultimately, a two-cell design was approved by OMB, permitting only before and after measures of the experimental group.

There are obvious abuses and excesses which can and have occurred in the use of human, control populations. The infamous withholding of medical care from a control group of syphilitic patients is a clear example. But it would appear that the government has been so sensitized by this scandal as to forbid *all* control group studies no matter how innocuous the benefit withheld. We believe that this is an important issue.

Privacy

The Privacy Act of 1974 (P.L. 93-579) was designed to provide certain safeguards for an individual against invasion of personal privacy by requiring Federal agencies and all those activities funded by such agencies to control the collection, maintenance, use, and dissemination of personal information so as to protect the privacy of the subject. The act established a Privacy Protection Study Commission to study and record data systems and to develop recommendations to the President and Congress regarding legislation that might be required to implement the intentions of the act. The Commission developed a summary of recommendations regarding research and statistical activities that clearly affect the maintenance and use of research data. It recommended that:

> The Congress provide by statute that no record or information contained therein collected or maintained for a research or statistical purpose under Federal authority or with Federal funds, be used in individually identifiable form to make any decisions to take any action directly affecting the individual to whom the record pertains, except within the context of the research plan or protocol, or with the specific authorization of such individual.

It goes on to recommend a number of other operational features, and in each the data gathered in federally financed research are covered. Therefore, contracts or grant-supported research outside of work done in agencies is affected. In Commission hearings no strong opinion was offered predicting that basic research would be hindered significantly by the regulations. Only time will tell whether statutes or regulations which might be adopted will have a hindering effect on research. It is safe to predict, however, that a variety of social science and behavioral science research methods will have to be changed if these recommended requirements become law. Anthropology and psychology societies have developed codes of ethics covering the use of human subjects and the use and protection of privacy in respect to the data generated in behavioral and anthropological research. The "Privacy and Behavioral Research" report cited above deals with this subject. This was also an investigative report making recommendations.

CHAPTER 8

INTERAGENCY COORDINATION OF BASIC RESEARCH

Coordination of the research and development activities of the Federal departments and agencies has been a matter of concern for many years to members of the executive and legislative branches of the Government and to members of the scientific community. On the whole, there appears to be a surprising degree of coordination, especially with respect to basic and applied research. This coordination is achieved by both formal and informal means, the latter being particularly important.

This chapter is concerned primarily with interagency coordination and does not attempt to look at questions relating to intra-agency coordination. Internal coordination of research activities is frequently the responsibility of a designated official such as the Under Secretary of Defense for Research and Engineering in the Department of Defense, the Assistant Secretary for Policy Development and Research in the Department of Housing and Urban Development, or the Assistant Secretary for Science and Technology in the Department of Commerce.

Definitions

The word "coordination" has different meanings for different people. To some, coordination connotes or implies direction and/or control. This connotation is responsible for a good deal of the confusion, misunderstanding, and apprehension associated with attempts by various bodies to coordinate Federal research programs. To others, coordination has seemed to be something less menacing, with connotations of cooperation and collaboration. To still others, who seek to quell apprehension and uncertainty, coordination has been equated with correlation, and the latter word has sometimes been substituted for the former.

Several definitions of coordination are referred to in an excellent Library of Congress report on interagency research coordination.[1] Haimann defines it as "the conscious process of assembling and synchronizing differentiated activities so that they function harmoniously in the attainment of organization objectives."[2] Mooney defines coordination as "the orderly arrangement of group effort, to provide unity of action in the pursuit of a common purpose."[3]

Brief History Since 1938

Whatever the perceptions and differences of opinion about its precise meaning, a general feeling of need for coordination of research and development programs has persisted for many years.

National Resources Committee

The National Resources Committee, the immediate predecessor of the National Resources Planning Board, expressed the need for coordination within the Government as early as 1938.

> Coordination between Federal research agencies is essential in the interest both of science and of efficiency. Coordination between research agencies serves both an administrative and scientific purpose. The administrative purpose is that of programming research activities to avoid duplication and to carry on service functions more effectively. The scientific purpose is to allocate research functions to those agencies best equipped to prosecute them, to keep workers in any given field informed of the activities of others in the same field, and to bring to bear on any specific problem the resources of all the sciences capable of contributing to a solution.
>
> Although the scientific work of the Federal Government is departmentalized and subdivided among numerous bureaus and offices, these functional divisions should not, and in the main do not, prevent concentration upon a single problem of the resources of many agencies. As the functions of the bureaus have become specialized, the machinery for cooperation and collaboration has grown up to a point of high oper-

[1] *Interagency Coordination of Federal Scientific Research and Development: The Federal Council for Science and Technology*, a report prepared for the Subcommittee on Domestic and International Scientific Planning and Analysis of the Committee on Science and Technology, U.S. House of Representatives, by the Science Policy Research Division, Congressional Research Service, Library of Congress, July 1976.

[2] Haimann Theo, and William G. Scott, *Management in the Modern Organization*, sec. ed. (Houghton Mifflin Co.: Boston, 1974), p. 124.

[3] Mooney, James D., *The Principles of Organization*, rev. ed. (Harper and Row: New York, 1974), p. 5.

ating efficiency. By means of joint committees or informal discussions, agencies dealing with similar problems avoid duplication and make more effective use of facilities and accumulated knowledge; by formal contract, often involving transfer of funds, specialized phases of a more general research problem may be investigated by one agency for another; and by loan or exchange of personnel, those scientific workers who are best fitted to conduct a given investigation may do so under the auspices of some bureau other than their own.[4]

NDRC and OSRD

The National Defense Research Committee (NDRC) was established by President Roosevelt in 1940, and was followed in 1941 by the establishment of the Office of Scientific Research and Development (OSRD). The latter was composed of a reconstituted NDRC and a new Committee on Medical Research. Coordination of wartime research and development functions was exercised by OSRD, its two constituent committees, the Advisory Council of OSRD, and by the Joint Committee on New Weapons and Equipment, consisting of the Director of OSRD and two military members, one from the Army and one from the Navy.

ICSRD and NSF

Three important reports in the immediate post-World War II period addressed the question of coordination of Federal scientific activities. These were the Kilgore report, "The Government's Wartime Research and Development, 1940-44," the Bush report, "Science—The Endless Frontier," and the Steelman report, "Science and Public Policy." The Kilgore report recommended that the coordination function be undertaken by a Federal research agency, whereas the Bush and Steelman reports urged that coordination be the responsibility of an interbureau or interdepartmental committee or council.

The Interdepartmental Committee on Scientific Research and Development (ICSRD) was established in 1947 (by Executive Order 9912) with two duties which relate primarily to the coordination function:

- Recommend steps to make the research and development programs of the Federal government most effective in the promotion of the national welfare (E.O. 9912, 3(a));
- Encourage collaboration among Federal agencies engaged in related scientific research and development (E.O. 9912, 3(e)).

The National Science Foundation Act of 1950 (Public Law 507) originally authorized and directed the Foundation:

> . . . to evaluate scientific research programs undertaken by agencies of the Federal Government, and to correlate the Foundation's scientific research programs with those undertaken by individuals and by public and private research groups (Sec. 3. (a) (6)).

This evaluation and correlation function was interpreted by some as being a coordination function that NSF was expected to exercise over the other Government agencies having scientific programs. This clause has been substantially modified over the years and now reads (1977):

> . . .to evaluate the status and needs of the various sciences as evidenced by programs, projects and studies undertaken by agencies of the Federal Government, by individuals, and by public and private research groups, employing by grant or contract such consulting services as it may deem necessary for the purpose of such evaluations; and to take into consideration the results of such evaluations in correlating the research and educational programs undertaken or supported by the Foundation with programs, projects, and studies undertaken by agencies of the Federal Government, by individuals and by public and private research groups (Sec. 3. (a) (5) as amended).

The evaluation and correlation function of NSF was extended when the Foundation was authorized to support applied research:

> In addition to the authority contained in subsections (a) and (b), the Foundation is authorized to initiate and support scientific research, including applied research, at academic and other nonprofit institutions. When so directed by the President, the Foundation is further authorized to support through other appropriate organizations, applied scientific research relevant to national problems involving the public interest. In exercising the authority contained in this subsection, the Foundation may employ by grant or contract such consulting services as it deems necessary, and shall coordinate and correlate its activities with respect to any such problem with other agencies of the Federal Government undertaking similar programs in that field (Sec. 3.(c)).

Federal Council for Science and Technology

Late in 1957 President Eisenhower appointed James R. Killian, Jr., to be a special assistant for

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[4] *Research—A National Resource: Relation of the Federal Government to Research,* a report of the National Resources Committee, December 1938.

science and technology and to serve as his science adviser. At about the same time the Science Advisory Committee in the Office of Defense Mobilization was transferred to the Executive Office of the President and transformed into the President's Science Advisory Committee. The PSAC Panel on Research Policy report, "Strengthening American Science," resulted in the establishment, in 1959, of the Federal Council for Science and Technology. Unexpectedly, Executive Order 10807, which established the Federal Council, also revoked Executive Order 9912 and thus terminated ICSRD.

The history of the FCST is described in detail in the previously cited report prepared by the Congressional Research Service of the Library of Congress. It covers three periods: (1) from 1959 to 1962, when the Office of Science and Technology was created in the Executive Office of the President; (2) from 1962 to 1973, when the Office of Science and Technology was abolished; and (3) from 1973 to 1976, when the Federal Council was located in the National Science Foundation.

Throughout this 17-year period the Federal Council operated with a wide variety of committees in order to carry out the functions listed in Executive Order 10807, as amended by Executive Order 11381, November 8, 1967. The coordination function is implicit in the following excerpts from E.O. 10807, as amended:

(1) Functions of Council
 (a) The Council shall consider problems and developments in the fields of science and technology and related activities affecting more than one Federal agency or concerning the overall advancement of the Nation's science and technology, and shall recommend policies and other measures
  (i) to provide more effective planning and administration of Federal scientific and technological programs,
  (ii) to identify research needs including areas of research requiring additional emphasis,
  (iii) to achieve more effective utilization of the scientific and technological resources and facilities of Federal agencies, including the elimination of unnecessary duplication, and
  (iv) to further international cooperation in science and technology.
 In developing such policies and measures the Council, after consulting, when considered appropriate by the Chairman, the National Academy of Sciences, the President's Science Advisory Committee, and other organizations, shall consider
  (i) the effects of Federal research and development policies and programs on non-Federal programs and institutions,
  (ii) long-range program plans designed to meet the scientific and technological needs of the Federal Government, including manpower and capital requirements, and
  (iii) the effects of non-Federal programs in science and technology upon Federal research and development policies and programs.
 (b) The Council shall consider and recommend measures for the effective implementation of Federal policies concerning the administration and conduct of Federal programs in science and technology.
(2) At least one such standing committee shall be composed of scientist-administrators representing Federal agencies, shall provide a forum for consideration of common administrative policies and procedures relating to Federal research and development activities and formulation of recommendations thereon, and shall perform such other related functions as may be assigned to it by the Chairman of the Council.
(3) The Council shall be advisory to the President and to the heads of Federal agencies represented on the Council; accordingly, this order shall not be construed as subjecting any agency, officer, or function to control by the Council.

Table 8.1 provides a composite list of all FCST committees, panels, groups, etc., established during the period 1959-1976. Table 8.2 shows which departments and agencies were members or observers of FCST committees or task forces in 1976.

The Federal Council for Science and Technology was abolished in 1976 when the Office of Science and Technology Policy (OSTP) was established in the Executive Office of the President in accordance with the provisions of the National Science and Technology Policy, Organization and Priorities Act of 1976 (Public Law 94-282). A President's Committee on Science and Technology (PCST) and a new Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) were established in OSTP, with FCCSET having essentially the same functions as FCST, which it replaced.

Reorganization Plan No. 1 of 1977

Reorganization Plan No. 1 of 1977, transmitted to the Congress on July 15, 1977, abolished both

Table 8.1—Federal council for science and technology committees and panels, groups, etc.

Name	Years (1959-1976) 59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76
Standing committee (from 1967—committee on federal laboratories)	E																	C
Technical committee on high energy physics	E										A[7]							
International committee	E														T[8]			
Coordinating committee on materials research and development	E										A[7]							
Interdepartmental committee for atmospheric sciences	E																	C
Interagency committee on oceanography	E								A									
Committee on long-range planning			E								A[7]							
Committee on natural resources			E				A											
Subcommittee on water resources research			E	M[1]														
Committee on water resources research				E														C
Committee on scientific information				E		M[2]												
Committee on scientific personnel				E			A[3]											
Ad hoc panel on transportation research					E	A[4]												
Patent advisory panel					E						M[9]							
Committee on behavioral sciences					E						A[7]							
Committee on scientific and technical information						E									T[10]			
Committee on government patent policy							E											C
Committee on academic science and engineering							E							I[11]				
Ad hoc working group on solid earth sciences								E	M[5]									
Committee on solid earth sciences									E		A[7]							
Committee on environmental quality									E			A						
Ad hoc interagency working group for earthquake research										M[6]								
Interagency upper mantle committee										M[6]								

Interagency arctic research coordinating committee	E								C
Ad hoc group on population research	E	A[12]							
FCST study group on DOD-domestic agency review		E/ A[12]							
Ad hoc committee on intergovernmental science relations		E			A				
Ad hoc committee on R&D in relation to environmental quality			E[13]	A[13]					
Interagency committee on marine science and engineering				E					C
Committee on RANN coordination				E		T[10]			
Interagency committee on excavation technology				E					C
Ad hoc committee on ecological research (joint FCST-CEQ)				E			A		
Committee on international transfer of technology				E			T[14]		
Committee on energy research and development goals				E		A			
Automation opportunities in the service sector				E				I[15]	
Committee on forecasting models					E		A		
Ad hoc committee on domestic technology transfer							E		C
Ad hoc committee on the international geodynamics project							E		C
Interagency coordinating committee for astronomy							E		C
Committee on materials							E		C
Interagency task force on inadvert. modific. of stratosphere								E	C
FCST operating committee								E	C
Ad hoc committee on social research and development								E	C
Committee on food research								E	C

Table 8.1—Federal council for science and technology committees and panels, groups, etc.—Continued

Name	Years (1959-1976) 59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76

Legend:
E = Established
C = Continuing
I = Inactive
M = Merged
A = Abolished
T = Transferred

1/ Merged into a new Committee on Water Resources Research
2/ Merged into a broadened new Committee on Scientific and Technical Information
3/ Functions taken over by Standing Committee
4/ Abolished when Department of Commerce assumed direct responsibility for this field
5/ Merged into Committee on Solid Earth Sciences
6/ Became subordinate groups of Committee on Solid Earth Sciences
7/ Abolished June 1969
8/ Transferred to Department of State, June 1973
9/ Merged into reorganized Committee on Government Patent Policy
10/ Transferred to National Science Foundation, June 1973
11/ Became inactive January 1, 1972
12/ Discontinued upon completion of its work
13/ Established 1970; to be disestablished upon publication of report 1971
14/ Transferred to Department of State
15/ Inactive following publication of report

Source: *Interagency Coordination of Federal Scientific Research and Development: The Federal Council for Science and Technology.* Report, Subcommittee on Domestic and International Scientific Planning and Analysis of the Committee on Science and Technology, U.S. House of Representatives, 94th Congress, GPO, July 1976.

Table 8.2—Membership on federal council for science and technology committee or task forces, 1976

DEPARTMENT OR AGENCY	Committees and Task Forces* IARC	ICCA	ICAS	CDTT	ICET	CFL	CFR	CGPP	CIGP	ICMSE	COM	FCSTOC	CSRD	ITFIMS	CWRR
State	M		M				M	M	M	M	M	M	O	M	O
AID													O		
USIA													O		
Defense	M/O	M	M	M	M	M	M	M			M	M	M	M	M
Army	O				M	M									
Corps of Engineers	M/O				M					M					
Navy	O	M			M	M				M					
Air Force						M									
ARPA													M		
Justice				M				M				O	M	M	
Interior			M		M	M	M	M			M	M	O		M
Geological Survey	M				M	M				M					
Bureau of Mines				M	M	M									
Agriculture	M		M	M	M	M	M	M			M	M	M	M	M
Commerce				M				M			M	M	M	M	
Patent Office								M							
NOAA	M	M	M/O			M	M			M					M
NBS		M		M		M									
Labor					M								M		
HEW	M			M		M	M	M	M	M	M	M	M	M	
HUD			O	M	M	M		M	O		M	M	M		M
Transportation	M		M	M	M	M		M		M	M	M		M	M
Fed. Railroad Adm.					M										
Fed. Highway Adm.				M	M										
OMB	O	O	O	M		O		O			M		O	O	
ACDA			O												
NASA	M	M	M	M	M	M		M		M	M	M	M	M	M
ERDA	M	M	M	M	M	M	M	M		M	M	M	M	M	M
NSF	M	M	M/O	M		O	M	M	M	M	M		M	M	M
STPO/STIA	O		O	M	M		M	O					M		
CEA			O	M											
CEQ	O			M										M	
FPC															
FEA	M			M									O		
EPA	M	O	M	M	M	M	M	M	M	M	M		M	M	M
VA													O		
SBA							M								M
TVA				M											M
GSA				M				M							
FCC			O												
Smithsonian		M		M		M				M			O		M
Con. Product Safety Comm.														M	
ACTION													O		
EEOC													O		
Com. on Civil Rights													O		
Fed. Res. Bd.													O		
Treasury													O		

Table 8.2—Membership on federal council for science and technology committee or task forces, 1976

DEPARTMENT OR AGENCY	Committees and Task Forces*														
	IARC	ICCA	ICAS	CDTT	ICET	CFL	CFR	CGPP	CIGP	ICMSE	COM	FCSTOC	CSRD	ITFIMS	CWRR
Domestic Council													O		
CSC						M									

M = Member/members

O = Observer

*Glossary (Committees and Task Forces)

IARC—Interagency Arctic Research Coordinating Committee; ICCA—Interagency Coordinating Committee for Astronomy; ICAS—Interdepartmental Committee for Atmospheric Sciences; CDTT—Committee on Domestic Technology Transfer (ad hoc); ICET—Interagency Committee on Excavation Technology; CFL—Committee on Federal Laboratories; CFR—Committee on Food Research; CGPP—Committee on Government Patent Policy; CIGP—Committee on the International Geodynamics Project (ad hoc); ICMSE—Interagency Committee on Marine Science and Engineering; COM—Committee on Materials; FCSTOC—FCST Operating Committee; CSRD—Committee on Social Research and Development (ad hoc); ITFIMS—Interagency Task Force on Inadvertent Modification of Stratosphere; CWRR—Committee on Water Resources Research.

Source: *Interagency Coordination of Federal Scientific Research and Development: The Federal Council for Science and Technology.* Report, Subcommittee on Domestic and International Scientific Planning and Analysis of the Committee on Science and Technology, U.S. House of Representatives, 94th Congress, GPO, July 1976.

the President's Committee on Science and Technology and the Federal Coordinating Council for Science, Engineering, and Technology, and transferred their functions to the President. FCCSET was reestablished by Executive Order 12039, dated February 24, 1978, under the chairmanship of the Director of the Office of Science and Technology Policy.

Office of Management and Budget

The role of the Office of Management and Budget (OMB) (formerly Bureau of the Budget) in the coordination of Federal scientific activities has been important in a number of ways. As final arbiter, except in rare instances, on the inclusion or exclusion of programs—and on the funds requested for them—in the President's budget, the examiners and other officials in OMB exercise decisive influence on the research programs of the Federal departments and agencies. The Steelman report had recommended that the Bureau of the Budget establish a unit for reviewing Federal research and development programs; the Bureau created a new functional category, "Education and General Research," for the FY 1948 budget. The first special analysis of Federal research and development funds appeared as Special Analysis H in the President's budget for FY 1955.

The Case for an R&D Budget

Willis H. Shapley discusses the question of whether there should be an "R&D Budget" for the Federal Government:[6]

> We shall begin by pointing out that the federal government does not have an "R&D Budget" as such. One may, perhaps, refer to the sum of all the amounts of R&D in the budget as an "R&D Budget," but this is misleading in that it implies essential features of a budget which do not apply to federal R&D. As we shall see, the total amount for R&D is not determined by a specific decision; there is no direct limitation on the total and no single central point of control; and trade-off type decisions within the total are generally not meaningful or feasible between separate major functional elements of the total.
>
> While OMB may monitor during the annual budget review an "R&D crosscut" summarizing all the principal R&D budgets, the total

[6] *Research and Development in the Federal Budget, FY 1977,* a report prepared for the Executive Officer and the Committee on Science and Public Policy, American Association for the Advancement of Science, by Willis H. Shapley, AAAS, 1976.

amount for R&D in the federal budget is actually the result of a large number of separate budgetary decisions in which the focus is primarily on the objectives of individual R&D programs and the missions to be served by them, not on their relationships to other R&D. Thus the budget for military R&D needs to be properly related to the overall defense budget, but does not have a meaningful relation to, for example, the budget for agricultural R&D.

The question of whether there should be an "R&D Budget" in a stronger sense is frequently raised. Discussions of general R&D policy sometimes seem to assume that this is desirable, a view that is strongly disputed by many other observers and participants. The basic questions relate to the organization and control of R&D; that is, the relative merits of (i) separate central control over R&D activities, and (ii) integration of R&D with the mission activities it supports. The first approach has been followed in the centralization of control over all R&D within the Department of Defense and the creation of specialized R&D agencies like OSRD, NASA, NSF, ERDA, and others. The other approach has been followed in most other agencies, where R&D is handled as a part of the broader mission activities it supports. Establishment of a separate "R&D Budget" would be a step toward central control of all federal R&D and could create difficult problems of divided responsibility. As a matter of sound administrative management, agency heads and their line managers must be responsible for their budgets. This means that all budgets, including R&D budgets, have to be determined primarily on an organizational basis; carving out a separate R&D budget under central control would divide responsibility and would undermine the position of the responsible agencies. Proposals for an "R&D Budget" that go beyond the OMB "crosscut" should be viewed with caution and full recognition of the broader needs of organization and management in the Executive Branch.

Agency Views on Coordination

Federal research agencies and the individuals responsible for their research programs view coordination in many ways. As a rough approximation, the mechanisms for coordination of research activities can be divided into two broad categories: formal and informal. The following tabulations in each category represent typical responses to questions concerning interagency consultation and coordination of effort on research projects. Although most of the responses referred primarily to "research," there was essentially unanimous agreement that the problem and the solutions were the same for both basic and applied research.

Formal Mechanisms

- FCST and FCCSET committees
- Memorandums of understanding
- Cooperative agreements
- Interagency groups, panels, committees, and boards
- NAS and NAE committees
- International treaties and international agreements
- Executive orders
- Legislative mandates
- Transfer of funds in support of programs of joint interest to two or more agencies
- Cross-agency representation on boards or councils of some agencies, e.g., Director of NSF on NCER.

Informal Mechanisms

- Ad hoc advisory committees
- Semiformal interagency coordinating groups
- Exchange of lists of research proposal receipts, status, and actions
- Requests to another agency to review research proposals
- Liaison membership on review committees or study sections
- Joint funding of research projects
- Ad hoc agreements
- Meetings, workshops, seminars, symposia, conferences
- Participation in meetings of professional scientific societies
- Informal scientist-to-scientist contacts
- Publication of papers in scientific journals
- Reading the scientific literature

The wide diversity of mechanisms used in a single agency for interagency consultation and coordination is illustrated by NOAA's response to the Board:

> The following list is intended to show the broad interagency involvement of NOAA programs. While most of these mechanisms relate to applied research, some relate to basic research as well:
>
> 1. Federal Coordinating Council for Science, Engineering, and Technology

2. Committee on International Environmental Affairs
    a. Subcommittee on Stratospheric Pollution
    b. Task Force II (deals with United Nations Environment Program)
3. Interdepartmental Committee for Atmospheric Sciences
    a. Panel on the Inadvertent Modification of Weather and Climate
    b. Climate Program Plan Drafting Group
    c. Ad Hoc Group to Outline a National Plan for Upper Atmosphere R&D
4. Federal Committee for Meteorological Services and Supporting Research
    a. Interdepartmental Committee for World Weather Programs
    b. Interdepartmental Committee for Applied Meteorological Services
    c. Interagency Committee for World Weather Programs
    d. Joint Committee for Space Environment Forecasting
    e. Working Group on Atmospheric Research Processing Centers
    f. Working Group for Monitoring the Stratosphere
5. Interdepartmental Board for the Cooperation of the National Oceanic and Atmospheric Administration with the Department of Defense
6. Interagency Committee for Marine Environmental Prediction
7. Federal Interagency Task Force on Inadvertent Modification of the Stratosphere
    a. Subcommittee on Biological and Climatic Effects Research
8. Biological and Climatic Effects Research Policy Group
9. DOC-NASA Satellite Program Review Board
10. Interagency Committee on Water Resources Research
11. Subcommittee on Hydrologic Research of the NOAA/USGS Committee on Hydrology
12. Landsat Interagency Decision Team
13. Interagency Arctic Research Coordination Committee
14. NASA Climate Plan User Working Group
15. NASA Climate Plan Science Working Group

Supplementing the above formal mechanisms there is a large number of information relationships between NOAA and research groups in the federal agencies, in addition to the interagency information transfer mechanisms such as the National Technical Information Service (NTIS) and the Smithsonian Science Information Exchange (SSIE).

The Environmental Data Service has input to interagency and international bodies supporting atmospheric and marine research programs. In this capacity, data exchange agreements are negotiated. In the Coastal Zone Management program, the basic mechanisms for coordination with other agencies is the review and comment process.

Some agencies, such as the State Department's Bureau of Oceans and International Environmental and Scientific Affairs (OES) and the Agency for International Development (AID), have responsibilities for international scientific activities and use both formal and informal mechanisms to achieve coordination and flow of information. OES is responsible for a number of science and technology agreements with foreign countries and has established a number of interagency bilateral working agreements to facilitate work on different projects. AID uses interagency service agreements in connection with its scientific activities; it also has formal agreements with foreign countries and with international agencies.

Formal interagency information transfer mechanisms include the National Technical Information Service (NTIS) in the Department of Commerce and the Smithsonian Science Information Exchange (SSIE). NTIS was established "to simplify and improve public access to Department of Commerce publications and to data files and scientific and technical reports produced by Federal agencies and their contractors." SSIE is a primary source for information on research in progress; it collects, indexes, stores, and retrieves information, on an annual basis, on about 125,000 Government and nongovernment research projects.

The Lead Agency Concept

The "lead agency" concept developed when each of several agencies which were supporting substantial program activities determined that overall program improvement was possible if the agency giving the greatest amount of support assumed responsibility for interagency coordination, generally through chairing a coordinating and policy committee or through some form of oversight. The "lead agency" approach to coordination of research projects appears to be effective in some cases and of limited effectiveness in others. The

following comments are quoted from agency submissions:

- *NOAA*—To coordinate related activity among several independent agencies the "lead agency" concept provides a focus and initiative that otherwise may not exist. It has limited effectiveness in areas that agencies perceive to be vital to their mission. It has the limitations of any "coordination" of independent agencies.
- *Navy*—The assignment of "lead agencies" for the development of specific technologies may sometimes be useful. Two technological areas in which the Office of Naval Research acts as lead agency and in which the concept has worked are superconducting thin film materials and superconducting electronics. There are other areas, however, in which the concept does not work well and, indeed, creates barriers to conducting research of vital importance to the Navy. These areas are typically broad ones such as fuels and other energy sources in which ERDA currently plays a leading developmental role but in which the Navy must retain scientific and technological expertise. Other areas in which the Navy's best interests are not served if the "lead agency" concept is pursued are pollution (EPA), oceanography (NSF), and space (NASA). In these areas, Navy laboratories, including the Naval Research Laboratory, must be active not only to address specific Navy problems and to contribute special expertise to the sciences and technologies involved, but also to provide windows on the areas and channels through which new information can be transmitted to the Navy for application.

  Another difficulty encountered in establishing a lead agency for a particular technology is that frequently the research necessary for that technology is too diffuse and multidisciplinary to be collected under one umbrella. Because new technologies spring from research which is, at first glance, unrelated to special technology, it is necessary to maintain research programs which can incorporate new ideas no matter in which agency they may arise. To the extent that the "lead agency" concept tends to channel ideas prematurely toward narrow technology goals rather than general applicability, it is detrimental to research.
- *NIH*—Collaboration at the research project level is typically between individual scientists or small groups interacting informally rather than on the basis of formal arrangements involving the NIH as an agency. There is a great deal of coordination at the program level, which involves exchange and joint planning and evaluation. An assessment of these activities is complex. On balance these coordination efforts are highly useful and desirable. Some are more "effective" than others, depending on the nature of the problem, personalities, political pressures and the extent to which problems of "turf" are involved.
- *NSF*—NSF is lead or executive agency under several international science agreements. Our agency is asked to take these roles because of its broad legislation, broad interests, and reputation in foreign countries for effective contracts with the U.S. scientific community. As executive agency, NSF cooperates with other concerned U.S. Government agencies or organizations in these ways:
  - plans activities for a program and coordinates U.S. part
  - deals directly with the foreign government on behalf of all U.S. agencies
  - seeks its own core support for the program, encourages other agencies to match
  - reports annually to the State Department.

  For example, NSF assisted the Tennessee Valley Authority in organizing energy-related activities under the U.S.-U.S.S.R. Cooperative Science Program. Under the same program, NSF negotiated with the Soviets in the area of science information for the Department of Commerce as well as for its own interests. NSF not only obtained a special allocation for this program but persuaded the Forest Service, U.S. Department of Agriculture to carry on activities under the Agreement without NSF support.

  Most cooperative research funded by NSF mirrors the domestic research priorities of NSF and is therefore a vital adjunct to domestic programs. However, many U.S. cooperative science agreements are with countries where more attention is paid to the development of technology than to science. Therefore, when we hold discussions leading to agreement with a partner country on scientific priorities, a mismatch of interest may be revealed. Foreign priorities are often for equal partnership in development-oriented or industrial research. NSF has limited abilities to respond to such interest, but mission-oriented agencies can often respond more appropriately.

CHAPTER 9

PRIORITIES AND GAP AREAS

This chapter presents the highlights of agency perceptions of priorities and gaps in their research agendas. No attempt has been made to correlate these from agency to agency or to rank them according to their importance.[1] Thus, no clear national agenda emerges from the agency lists. But they do mention or have a clear relationship to a number of problem areas that appear to merit national attention and that require basic research (if for no other reason than to complete our understanding of the problem). The following are illustrative:

- Earthquakes (the House of Representatives has already recognized the need for basic research in this area in the Earthquake Hazards Reduction Act of 1977. Two agencies—the National Science Foundation and the U.S. Geological Survey—are currently addressing this problem).[2]
- Climate and weather (the House of Representatives also calls for a basic research element in the National Climate Program bill passed last year. Eight agencies are currently scheduled for research initiatives in these areas: NOAA—the lead agency—and NASA, NSF, EPA, and the Departments of Defense, Energy, Agriculture, and Interior.[3]
- The brain and nervous system (the President's Biomedical Research Panel, for instance, states that this area may be "the ultimate challenge to biomedical research representing the very pinnacle of our understanding of the human organism")
- Urban revitalization
- Poverty
- Public transportation and traffic control
- Crime and criminals
- Upper atmosphere
- Less developed countries
- Nutrition
- Mental health.

Besides these broad problem areas, it is clear from example after example that basic research has a high priority in the accomplishment of many specific agency missions. In the presentation of the agency priorities below, research areas are classified where possible by science fields and subfields and priority areas are divided between short- and long-term. Areas in which gaps or underfunding are reported are then listed.

Further details on the priorities and gaps of each agency's research agenda are given in the "Current and Future Emphasis" sections of the agency submissions in Part I, although in some of the shorter submissions no such separate subtitle appears. In some cases, the agencies make the distinction between basic and applied research; in others, the distinction is either blurred or not made at all. Nor do the agencies always distinguish between short- and long-term priorities as requested by the Board (see Appendix C on methodology used in preparation of the report, especially Exhibit 4). The gap areas were reported in response to the Board's question: "What promising or vital areas of research, not now supported but involving basic research, warrant increased emphasis and support by your agency?"

Department of Agriculture

The following examples are areas of science in which a basic research approach is required.

[1]No attempt has been made to rank priorities either within an agency or among the responding agencies. The question of priorities within a given field of science is discussed by William W. Lowrance in "The NAS Surveys of Fundamental Research 1961-1974, in Retrospect," in the September 23, 1977, issue of *Science* (p. 1254). Based on the 10 surveys of major fields of science conducted by committees of the National Academy of Sciences from 1962 through 1974, this article states that the physics survey committee developed a method of setting priorities, but adds:

> Never, in these surveys or elsewhere, has a perfect program been developed for deciding on the relative importance of different research programs.

In its submission in Part I, HEW makes the point that priority setting becomes increasingly difficult as the time span for planning increases. An example of a procedure for setting priorities is contained in *World Food and Nutrition Study: Potential Contributions of Research,* Steering Committee, NRC Study on World Food and Nutrition, Commission on International Relations of the National Research Council (National Academy of Sciences: Washington, D.C., 1977). First, 12 interdisciplinary study teams produced a list of more than 100 priority research areas. Then the list was analyzed by another study team and by the Steering Committee itself. The end result was a list of 22 priority research areas, but no ranking was made among the areas. It is interesting to note the great similarity and overlap between the NRC's selection and the 30 priority areas in basic research identified by the Department of Agriculture.

[2]*Special Analyses, Budget of the United States Government, Fiscal Year 1979* (GPO: Washington, 1978), p. 308.

[3]Ibid.

Advances in knowledge in such areas are important to high-priority thrusts in agricultural and forestry technology or to advances in institutional arrangements and in the quality of life in rural communities and homes.

List of Priorities

Agricultural Research

- Nitrogen fixation
- Photosynthesis
- Genetic engineering for plants
- Recombinant DNA
- Plant protection
- Respiratory and enteric diseases
- Hormonal control of growth and reproduction
- Physiological control of cellular growth in animals
- Human nutrition
- Basic properties of food systems
- Terrestrial and aquatic ecology as related to atmospheric transfer and precipitation systems
- Crop growth models
- Characterization of new pathogenic nucleic acid moieties
- Alternative sources of energy
- Salt control of irrigation return flows

Forest Research

- Biomass productivity and fuel combustion efficiency
- Combustion products and their photochemistry
- Wood structure and durability
- Nutrient gains and losses associated with intensive forest management
- Forest fire effects
- Chemical derivatives from wood
- Methodologies for measuring non-timber goods and services of forest rangelands

Social Science Research

- Consequences of and adjustments to price instability
- Comprehensive forecasting and projection models
- World food situation and country market studies
- Population and migration
- Regional and rural development
- Food, nutrition, and income
- Capital and credit
- Impact assessment.

Department of Commerce

National Bureau of Standards (NBS)

In the future as in the past, measurement science will be the principal driving force for basic research at NBS. The needs will be for more precise values of the basic physical constants, for more sophisticated chemical analysis, for more accurate characterization of materials, and for more accurate and economical techniques for making all sorts of physical measurements of temperature, sound, electromagnetic fields, etc. In pursuit of this challenge, NBS expects to continue to operate at the forefront of the physical science disciplines and integrate research in the disciplines to provide the measurement services needed in areas of major national concern (e.g., nuclear safeguards, energy, technical bases for government regulation, health, safety, and technology underlying better consumer information).

List of Priorities

- Measurement science
  —Organic analysis
  —Instrumentation
- Atomic and molecular science (chemical reaction rates, ozone layer dynamics, very high temperature plasmas, new lasers)
- Science of surfaces (catalysis, corrosion)
- Materials science (phase transitions, kinetics, structure, deformation, fracture, high temperature, and extreme environments)
- Fire research
- Nuclear science
- Mathematics and computer science (analysis, statistics, large scale mathematical models, sampling theory)
- Thermal studies (nonequilibrium systems)
- Buildings research
- Electronic technology (electronic devices at the micrometer and submicrometer levels).

List of Gap Areas

- Sensitive, accurate techniques for determination of low concentrations of organic compounds in diverse media
- Accelerator with much higher duty cycle than the present NBS LINAC for detection of nuclear decay products in coincidence experiments
- Measurement techniques to meet requirements of submicrometer microcircuit devices and beyond

- Overall resources for the broad spectrum of basic research, free from competition from short-term applied projects
- Thermal studies (nonequilibrium systems problems constitute one of the classic areas of science where a fully satisfying conceptual basis is still lacking. Collaborative interactions with atomic and molecular science and phase transformation in materials give this area special interest).

National Oceanic and Atmospheric Administration (NOAA)

NOAA's research priorities for the next 3 to 10 years are listed below.

List of Priorities (short- and long-term)

- Oceans (climate variation, effects of pollutants)
- Mesoscale weather (forecasting techniques, long-range forecasting, severe storms, cloud microphysics)
- Geochemical cycles (CO_2 and nitrogen in the atmosphere, oceans and biosphere, stratosphere and upper stratosphere)
- Continental shelf, coastal estuarine processes
- Fine structure of the geoid
- Global weather experiment
- Climate (effects of aerosols, human impact, diagnostic research)
- Weather modification
- Sea-air interaction.

List of Gap Areas

- Carbon dioxide in the oceans and biosphere (measurement and analysis to understand buffering of atmospheric carbon dioxide by oceans and biosphere)
- Mesoscale atmospheric processes
- Role of oceans in climatic variation
- Ocean dynamics and coastal processes (e g., rate of change in elevation and position of the U.S. continental shelf region, polar motion, and bathymetric forms—their origins and association with catastrophic submarine events)
- Climate diagnostics
- Stochastic processes in hydrologic forecasts.

Office of Telecommunications

The research and engineering arm of the Institute of Telecommunication Sciences supports research to increase the availability of usable spectrum and to improve the telecommunication system. Its basic research priorities are in the wave transmission area.

List of Priorities

- Electromagnetic wave transmission research (propagation, attenuation, scattering, ducting, refraction)
- Transmission loss through the atmosphere (distortion, effects of rain on microwave paths, predictive techniques)
- Mutual interference between systems and subsystems.

Maritime Administration (MarAd)

Basic research in MarAd emphasizes the naval architecture technologies of structures, hydrodynamics, and propulsions.

List of Priorities

- Structures (effects of sea loads and vibrations)
- Hydrodynamics (new hull and ship forms, human factors studies, ship automation, wave heights and their effect on ship bending, effects of propeller shape on transmission of vibration)
- Propulsors (advanced propeller design, materials).

Department of Defense

Army

The Department of the Army has established several areas of emphasis in basic research to respond to Army user needs and to indicate to Army laboratories the areas where research is especially needed.

List of Priorities (short-term)

- Millimeter and submillimeter wave radiation that can penetrate fogs and battlefield smokes
- Smokes and aerosols
- Target and background signatures (more comprehensive compilation and analysis)
- Wear and erosion research (to meet requirements for higher muzzle velocities, longer ranges, and higher rates of fire)

- Analytical and predictive techniques for more effective armor penetrators
- Model for predicting ignition and combustion processes in gun propellants.

List of Priorities (long-term)

- Atmospheric sciences contributing to the Army smoke program
- Food and ration research
- Electrically small, active antennas
- Wear and erosion (by hot gases and dust)
- Mathematical analysis of nonlinear systems
- Dynamic loading of structures and materials
- Materials research relating to four generic weapons systems: aircraft, armament, armor, and missiles
- Improvement of helicopter performance
- Combustion processes in engines and propellants
- Submillimeter technology
- Fire safe fuels
- Materials research
- Medical research
- Organizational effectiveness
- Ice adhesion.

List of Gap Areas[4]

- Venereal disease
- Drug abuse
- Basic immunology.

Navy

The programs sponsored by the Office of Naval Research (ONR) usually fall in areas nearer the frontiers of science with the longer term payoff, while those programs managed by the Systems Command and other organizations within the Navy Material Command are usually more closely coupled to direct requirements. The areas listed below are important from one or both of the above viewpoints.

List of Priorities

Physics

- Energetic interactions of plasmas, ions, atoms, and molecules
- Excited states of atoms and molecules
- Interactions of relativistic electron beams with electromagnetic fields and radiation
- Laser physics

Electronics and Solid State

- Physics of solid state surfaces and interfaces
- Rational fault analyses
- Superconductive electronics

Mathematics and Information Sciences

- Artificial intelligence
- Acoustic transmission models
- Large-scale numerical computation
- Large-scale systems
- Theoretical (mathematical) acoustics

Biology and Medicine

- Underwater physiology
- Electromagnetic field effects
- Ship motion biophysics

Psychological Sciences

- Human adaptability
- Cognitive processes
- Behavioral research
- Effects of advanced technologies

Earth Sciences

- Research in the Eurasian Basin
- Coastal geography
- Remote sensing

Materials

- Degradation research
- Basic electrochemistry
- Energy-dense materials
- Amorphous metals and alloys.

Ocean Sciences

- Synoptic remote sensing by satellites
- Development of models to predict upper ocean variability
- Basic biologic and chemical oceanography.

List of Gap Areas

Biology and Medicine

- Effects of ship motion on people
- Electromagnetic field effects
- Underwater physiology

Psychology

- Improving crew, group, team, and unit training through research which considers human interaction variables
- Effects of advanced technologies on operational and maintenance tasks and skill requirements

[4]The Army has been enjoined by Congress from conducting research in these areas.

Earth Sciences
- Oceanographic experiments (using direct links between research vessels and satellite remote sensing systems)
- Environmental sensor systems (*in situ*)
- Environmental effects of laser and infrared technology

Materials
- Less expensive and less sophisticated equipment for chemical analysis and surface chemistry (existing equipment is frequently beyond the means of innovative young scientists just beginning their careers)
- Amorphous metals (major impact in the magnet applications area is seen)

Ocean Science
- Physical oceanography (on the threshold of a breakthrough in understanding of ocean weather, i.e., the synoptic or instantaneous picture of ocean variability)
- Oceanic biology and chemistry (increased understanding of life cycles of boring and fouling organisms and the chemical properties of sea water).

Air Force

The Department of the Air Force funding for the next 3 years places the most funds in the areas of materials, mechanics, electronics, chemistry, mathematics, and physics. An intermediate level of funding is provided for energy conservation, atmospheric sciences, astronomy, and astrophysics. Research in biological and medical sciences, human resources, and terrestrial sciences receives the lowest level of funding. These allocations do not suggest the absolute priority of each area, but rather an appropriate mix of areas of priority.

List of Priorities

Aerospace Sciences
- Turbulence and transonic dynamics
- Heat transfer, turbine blade cooling, and temperature distribution
- Environmental effects on composites, and crack and failure mechanisms in metallic and composite structures

Chemistry and Materials Sciences
- Surface phenomena and interactions between surfaces
- High-temperature, high-strength materials
- Relationship of processability to morphology and microstructure which control the properties of polymeric materials

Electronic and Solid State Sciences
- High-power microwave tube research
- Low-cost inertial sensing
- Structural materials processing

Life Sciences
- Human operator performance modeling
- Environmental protection and toxicological hazards
- Simulators for training

Mathematical and Information Sciences
- Logistics/reliability
- Applications of microprocessors
- Software technology

Physics
- High-energy charged particle beams
- High-average power tunable lasers
- High-power incoherent sources.

List of Gap Areas[5]
- Greater growth in the turbulence and composite structure programs
- Research in adhesion to understand the nature of bonding between protective coatings and films and various substrates
- Dynamics and spectroscopy of new molecular systems for new electronic transition lasers
- Nondestructive evaluation of both metals and ceramics
- Human factors in the design of aerospace systems
- Identification of factors influencing simulator training effectiveness
- Probability theory and statistics applied to logistics and reliability problems
- Fault-tolerant systems design
- Conventional weapons phenomenology
- Visible and near-IR laser optics in the areas of sources, tunability, and geometry.

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[5]The Air Force submission (Part I) stated that these areas warranted increased emphasis. Some of the areas are repeated from the priorities list because it was felt that even more resources could be profitably expended on them.

Defense Advanced Research Projects Agency (DARPA)

Since this agency's mission is to develop long-range "high-payoff" technologies that are not within the purview of specific military services, it does not support basic research for the accumulation of abstract knowledge; but it does support a fundamental research program to provide a foundation for its major developmental thrusts.

List of Priorities (short-term)

- Materials sciences (electronic and electro-optical materials and techniques for cutting costs of finished structural components)
- Information processing techniques (with emphasis on those applicable to command, control, and communications technology).

Department of Health, Education and Welfare (HEW)

Alcohol, Drug Abuse, and Mental Health Administration

The Alcohol, Drug Abuse, and Mental Health Administration (ADAMHA) has three institutes to carry out its programs: the National Institute on Alcohol Abuse and Alcoholism (NIAAA), the National Institute on Drug Abuse (NIDA), and the National Institute of Mental Health (NIMH). ADAMHA expects to support research broadly within the areas defined by its member institutes, but the specific subareas must depend upon new advances and developments.

List of Priorities

NIAAA

- Central nervous system (effects of alcohol on brain cell membranes, neurochemistry, pharmacokinetics of alcohol)
- Nutrition and the gastrointestinal tract (damage to the gastric mucosa, malabsorption of vitamins and other nutrients)
- Endocrine system (hormonal control of water and mineral balance, endocrine-alcohol research)

NIDA

- Endorphin research (mechanisms of action of narcotic drugs, processes that control normal behavior and mental health)
- Genetic and developmental studies (genetic, mutagenic, and reproductive effects associated with abuse of drugs)
- Inhalant abuse (drug interactions, potential interactions with other agents and conditions, e.g., barbiturates and malnutrition)
- Health consequences of chronic marihuana use

NIMH[6]

- Basic biological and developmental studies (brain amine systems, enzyme levels in mental patients, behavioral genetics, neurological and chemical bases for abnormal psychological effects)
- Early adolescent psychobiology and development (endocrine and bodily changes of puberty, along with concomitant emotional and behavioral changes).

National Institutes of Health (NIH)

Several areas of basic research in biology and medicine are moving forward rapidly and are generally considered to be very promising. Genetics, immunology, virology, and cell biology are such areas which are basic to our understanding of virtually all disease processes, and thus are represented in the research programs of most of the Institutes at NIH. The neurosciences also are receiving more attention in view of their enormous potential.

List of Priorities

- Genetics (molecular mechanisms involved in inheritance and transmission of information from parent to offspring, regulation and control of genetic processes, gene mapping on chromosomes, recombinant DNA research)
- Immunology (structures of antibodies, cell generation of antibodies, immunologic aspects of noninfectious diseases, e.g., arthritis and cancer)
- Virology (linkage of viruses to cancer, degenerative diseases of the central nervous system, biological processes in simple cells)

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[6]An NIMH task force stated that it would be unwise for NIMH to set specific priorities for research such as targeting one type of mental illness over another (see the NIMH section of Part I).

- Cell biology (cell membranes, flow of substances across cell membranes, cell structure, abnormalities in cell constituents, regulatory processes in cells)
- Neurosciences (a broad spectrum of investigations).

List of Gap Areas

- Neurobiology (how the brain and nervous system develop, how they function in health and disease, how thought occurs, how memory is stored, how we reason, how we are motivated, and how we interact with our physical and social environment. (For more detail, see national priority list at the beginning of this chapter.)

National Institute of Education (NIE)

The National Institute of Education has outlined research priorities that emphasize the understanding and measurement of the learning process and the development of means to identify and integrate the needs of both the individual student and the community to which he belongs.

List of Priorities

- Basic skills (learning, teaching, measurement of achievement in reading, writing, and basic mathematics, and educational standards)
- Finance and productivity
- School productivity
- School capacity for problem solving
- Educational equity
- Education and work
- Dissemination and resources.

Department of Housing and Urban Development (HUD)

List of Priorities

- Causes and means of control of housing costs
- Alternative mechanisms for financing subsidized housing to encourage better maintenance
- Ways to assist older cities in their economic development and financial problems
- New approaches to providing housing to the elderly and handicapped
- Neighborhood reinvestment and revitalization
- Procedures for selecting sites for subsidized housing and, more generally, for fostering stable racial and economic integration.

List of Gap Areas[7]

- Homeownership (e.g., whether housing is a "merit good," i.e., a product or service that deserves community support or funding above the value individual users might place upon it)
- Equal opportunity goals in HUD projects (do they provide role models for upward mobility and other benefits to the less fortunate)
- Effects of local and Federal tax policies on investment incentives in rental property
- Urban property rehabilitation (e.g., whether current practices have unwanted side effects, such as family relocation problems and small business disruption).

Department of the Interior

Bureau of Mines

The Bureau of Mines sponsors programs of basic research that are relevant to issues such as production of minerals, minimization of mineral waste, and environmentally acceptable systems of mineral supply, processing, usage, and disposal.

List of Priorities (short-term)

- Fundamental thermodynamic data and processing evaluations essential to the development of minerals processing technology
- Improved phosphate rock processing methods to improve recovery, reduce losses, control contaminants, and minimize slimes disposal problems
- A sound data base of mineral reserves, production, and consumption for determining longer range priorities
- Improved techniques for detecting impending rock bursts
- Improved fire suppression systems for mines

[7]These are mentioned as basic topics that provide opportunities for future research. See HUD submission, Part I, for further details.

- Improved processing technology for the prompt, economical recovery of copper and byproduct metals from ores, concentrates, and mine wastes
- Technologies for recovering alumina from domestic nonbauxitic resources to lessen U.S. dependence on imported bauxite and alumina
- Improved beneficiation methods for recovering nonmetallic minerals from domestic ores and/or mineral wastes
- Improved technology for recovering uranium from various low-grade, domestic refractory carboniferous and siliceous resources
- Basic physical/chemical data in support of the alumina miniplant project
- Evaluation of wet high-intensity magnetic separators as a means of concentrating iron-bearing materials
- Application of advanced techniques to improve concentration of chromite from complex domestic sources
- Application of extraction technology to 0.01 percent uranium resources
- Methods for identifying, measuring, and controlling fugitive and accessory elements and compounds that are present in minerals processing systems and pass through into the waste streams or atmosphere.

List of Priorities (long-term)

- Wider uses for more abundant domestic minerals as substitutes for critical materials and commodities in short supply
- Economic methods to recover minerals and metals from domestic ores of progressively lower grade and complexity
- Technologies to facilitate the complete recovery of minerals now wasted during processing
- Less-energy intensive metallurgical processes or use of low-cost energy sources
- Technology to increase the portion of U.S. metal and mineral needs met by secondary resources
- Recycling metal and nonmetallic materials from industrial and obsolete consumer scrap materials (recovery techniques and incentives)
- Improved metallurgical processing technology base for preventing environmental degradation without unnecessarily restricting efforts by the minerals industry to meet the Nation's mineral needs
- Improved processing technology for minimizing undesirable environmental effects
- Expanded use of secondary materials in various metal alloys or nonmetal products (evaluation, demonstration, and promotion)
- Identification of potential scrap materials to allow early development of processing and recovery techniques.

List of Gap Areas

- Deep brine scaling mechanisms and kinetics
- Simulation of experimental metallurgical and engineering research using computer modeling
- Magnetic and electrostatic advanced mechanisms that have potential for separation of the mineral constituents of low-grade and complex ore.

U. S. Geological Survey (USGS)

The U.S. Geological Survey is charged with (1) increasing knowledge about U.S. earth resources and geological processes that affect land use and (2) classifying Federal lands and supervising mineral lease development on Federal and Indian lands. USGS basic research interests reflect these dual responsibilities. Priorities are founded on basic agency mission goals and are tempered by congressional mandates, executive directives, cooperative agency needs, and feedback from various review groups.

List of Priorities (current and short-term)

- Improved mineral and energy resources assessment methods
- Improved understanding of geodynamics—the forces and processes from within the Earth that affect crustal features, such as the continental plates and the oceanic basins
- Improved earth sciences information dissemination
- Improved methods of predicting and assessing the occurrence and effects of geologic hazards such as earthquakes, volcanic eruptions, and landslides
- Description of surface- and groundwater transport of solutes
- Description of the dynamics of ecological systems, especially with regard to estuaries
- Development of interdisciplinary approaches to the understanding of wa-

ter quality, including biological controls of heavy metals in sediment
- Improved water quality sensor technology
- Development of a system for aerial profiling of terrain to establish ground position with an accuracy of 3 meters horizontally and 0.15 meters vertically
- Development of a digital cartographic data bank for computer-controlled storage, processing, and retrieval in various forms of information shown on general purpose topographic and land-use and land-cover maps
- Determining Earth natural resources and physical conditions using remote sensing techniques.

List of Gap Areas
- Cyclic changes in climate
- Paleoclimate of ancient land areas
- Stochastic hydrology
- Basic physical properties of water.

National Park Service

The National Park Service's basic research aims at attaining an understanding of the basic ecology of the national park system.

List of Priorities
- Basic ecology of the national park system (especially assembly and continuous updating of retrievably stored basic resource inventories for all natural areas in the system)
- Development of a valid urban ecology
- Inquiry into naturally occurring radionuclides in caves
- Grizzly bear ecology
- Barrier island dynamics.

List of Gap Areas
- Ethological studies of the major animal species in the national parks (e.g., bears, goats, elk, moose, wolves, and birds).

Fish and Wildlife Service

Research of the Fish and Wildlife Service emphasizes understanding the life systems of species of flora and fauna—endangered or not—and the effects on those species of man's activities to insure better management of wildlife resources.

List of Priorities
- Effects of contaminants and their interaction on wildlife to protect the resource, whether as species, populations, or entire ecological communities
- The full impact on fish and wildlife resources and their habitat of water and related land resource projects conducted under Federal auspices or permits
- Determining the environmental issues of critical importance to strengthen the capability of the Service to provide ecological information needed in connection with accelerated development of energy resources
- Understanding the life histories of endangered species and factors that threaten the Nation's endangered flora and fauna and their ecosystems
- Migratory birds, especially marine and coastal species (identify both their species characteristics and those populations needing special protection or management considerations)
- Marine mammals (biological and management needs, distribution abundance, population status, and ecological relationships)
- Evaluation of wildlife-caused damages and hazards and of the development of more humane, selective, effective, and safe animal damage control techniques
- Diseases of free-ranging populations of anadromous fish species, effects of environmental changes caused by man on these populations, and development of hatchery fish more capable of surviving in natural environments
- The Great Lakes and determination of the effects of environmental contaminants on their fisheries
- Efficacy and safety of fish pesticides and drugs in order to reach full compliance with Public Law 92-516.

List of Gap Areas
- The fundamental habitat requirements and population dynamics of a wide range of nongame fish and wildlife that are not now threatened or endangered.

Office of Water Research and Technology (OWRT)

The Office of Water Research and Technology supports basic research with the potential to contribute to the solution of water-related problems.

List of Priorities (short-term)

- Research supporting the Department's mission and current objectives (promotion of water use efficiencies; protection of the water-based environment; improving water resources planning and management; solving energy-related problems involving water considerations; aiding Indian self-determination through improved water development and management on reservations)
- Research to solve or mitigate other critical water-related problems of the States and regions of the Nation
- Research in support of saline water conversion.

List of Priorities (long-term)

- Water quantity problems (control of excess water, water supply augmentation and conservation)
- Water quality problems (control of entering pollutants, effects of pollution, water treatment, waste disposal)
- Environmental impacts (economic, ecosystem, and public welfare effects)
- Water planning and management (institutions, methods and procedures, basic data).

List of Gap Areas

- New processes for water renovation or desalination
- Reuse of water from agricultural, municipal, and industrial wastes.

Bureau of Reclamation

Although most of the Bureau's research is project-oriented and applied, it supports basic research as a component of mission-oriented research activities.

List of Priorities

- Environmental problems related to water resources development
- Energy-related problems
- Automation of power and water systems
- Conservation of existing water supplies
- Atmospheric water resources management (especially development of technology for management of winter orographic and summer convective precipitation).

List of Gap Areas[8]

- Basic principles affecting downwind precipitation
- Basic principles relating precipitation to long period changes in the environment
- Basic principles relating to statistical evaluation of nonrandomized experiments, ice nucleation mechanisms, numerical methods used to simulate physical processes in multidimensional cloud system models, modeling of dynamical atmospheric processes, parameterization of physical processes in numerical models, short-term forecasting of precipitation and precipitation mechanisms, identification and use of predictor variables and covariants in experimental evaluation of precipitation modification experiments, and the effect of precipitation amount, timing, duration, distribution, and intensity on agricultural crop production.

Department of Justice

National Institute of Law Enforcement and Criminal Justice (NILECJ)

Future research by the National Institute of Law Enforcement and Criminal Justice will emphasize development of means of crime prevention through an understanding of the factors influencing criminal behavior as well as assessment of the quality of the criminal justice system.

List of Priorities (long-term)

- Correlates and determinants of criminal behavior
- Deterrence
- Community crime prevention
- Violent crime and the violent offender
- Career criminals and habitual offenders
- Performance standards and measurement of criminal justice
- Management and utilization of police resources
- Court management
- Sentencing
- Rehabilitation.

[8]Areas in the Atmospheric Water Resources Management Project that warrant increased emphasis and support.

Department of Labor

Department of Labor research activities focus on the assessment of labor- and management-related problems and the development of improved procedures for their solution.

List of Priorities (short-term)

- Public employee labor relations
- Improving collective bargaining and the means of resolving labor disputes.

List of Priorities (long-term)

- Adaptation of labor-management relations policies and strategies and union structure to major external stimuli such as inflation, unemployment, and the energy crisis
- Extra-negotiating means of resolving certain labor-management problems not readily susceptible to collective bargaining (e.g., tripartite or bilateral industry committees)
- Assessment of union democracy after two decades of the Labor-Management Reporting and Disclosure Act of 1959.

List of Gap Areas

- Collective bargaining and labor-management relations in nonprofit organizations
- Impact of foreign-owned business on American industrial relations
- Causes of voluntary changes in impasse procedures in Canadian federal employment.

Department of State

Bureau of Oceans and International Environmental and Scientific Affairs

The purposes of the basic research work of the Department of State are to advance and order data, explanation, and methods in fields of knowledge (the sciences and the humanities, disciplinary and multidisciplinary) that are selected because they illuminate matters that in the future will affect unspecified policy choices.

The Bureau notes the importance of both basic and applied research in the conduct of the Nation's foreign affairs and in the coordination of its foreign policy. Areas of investigation from which the Department can benefit are listed below.

List of Priorities

- Impact of modern cultural and educational systems
- Causes of ethnic and cultural conflicts
- Major variables in attitudes toward perceptions about people of other cultures, religions, and nationalities.

List of Gap Areas

- Advanced foreign affairs and foreign areas research.

Agency for International Development (AID)

Although AID states that it supports no basic research, it adds that "research for new knowledge and its application are vital to solving problems of the poor in developing countries," and that it "clearly recognizes the importance of a broad research and development program and its continuing dependence on both the Nation's fund of basic research and its extensive technology."

List of Priorities

- Agriculture
- Health
- Industry
- Economics
- Education
- Nutrition
- Population
- Social development.

List of Gap Areas[9]

- Understanding of social, behavioral, and cultural dynamics involved in efforts to implement policy and program applications
- Approaches to facilitate greater participation by affected people in the identification, development, and institutionalization of problem-solving techniques for self-help
- Greater utilization of research findings through continuing, adaptive follow-through from the research stage to acceptable usage in local environments.

Department of Transportation (DOT)

Basic research constitutes only a small portion of the Department's total R&D activities and is

[9]The AID submission presented these as "a number of problem areas in which more attention to basic research would undoubtedly provide more critical knowledge."

not targeted toward a specific application or problem solution but is supportive of the overall mission of DOT. This definition implies that the applicability of the research is potentially long-range and broad in spectrum.

List of Basic Research Topics[10]

- Advanced fixed-guideway systems (merits and demerits of different vehicle/guideway concepts)
- Large-scale network flow problems (new mathematical techniques that would contribute to transportation theory as well as applications)
- Impacts of transportation upon the spatial distribution of economic and social activities either regionally or nationally (understanding of the relationships between transportation, spatial form, and quality of life).

Energy Research and Development Administration (ERDA)

Basic research represents only "a modest fraction" of ERDA's total R&D work, but the agency (now part of the Department of Energy) stated that it "is making a substantial commitment to basic research."

List of Priorities[11]

Chemical Sciences

- Fossil fuel chemistry (coal and its constituents, catalysts)
- Combustion (short-lived reaction products, measurement of turbulence and reaction rates)
- Photoconversion (artificial photosynthesis, photochemical generation of fuels, and photogalvanic generation of electricity)

Materials Sciences

- Electrical conduction in materials
- Metals and ceramics for high-temperature applications
- Semiconductors for solar energy applications
- Superionic materials for batteries
- Electrical conduction in ceramics for magnetohydrodynamic and fusion energy applications
- Superconductors for electrical storage and transmission
- Synchrotron radiation facility for research in materials, molecular, and life sciences

Geosciences

High-Energy and Nuclear Physics

- Construction (underway) of ISABELLE colliding beam facility (high-energy physics)
- Additional stage of acceleration for the Holifield Heavy Ion Facility (heavy ion physics)

General Life Sciences

- Organic systems with rapid cell replacement
- Model *in vitro* cell systems
- Damage indicators
- Types of damage and repair
- Relating animal data to man
- Bases for new screening and damage detection methods.

Environmental Protection Agency (EPA)

The future research work of EPA will continue to emphasize identification of potentially hazardous substances and processes and development of methods for measuring their environmental effects.

List of Priorities (long-term)[12]

Health Effects, Air Exposure

- Exposure-response data for pollutants
- Potentially dangerous (to man) trace substances, hazardous materials, and unsuspected toxic substances
- Interactions of pollutants and multiple environment stress factors
- Indoor pollutants

[10]The DOT submission in Part I does not list any basic research for current and future emphasis. These examples, DOT says, "illustrate the nature of transportation basic research and its potential role in support of the Department's various missions. . . (but) are not major research efforts."

[11]ERDA stated that it made no attempt to present a comprehensive list of areas of future emphasis. Its submission was being prepared as the new Department of Energy was being created.

[12]In EPA's 5-year plan.

Toxic Substances

- Carcinogenicity and toxicity of fibrous amphiboles
- Biochemical methods for screening organic and inorganic pollutants
- Epidemiological research on correlation of cancer and other chronic diseases with environmental pollution
- Biological monitoring and tissue archiving

Ecosystems Research

- Measurement of overall pollution stress and impacts of single and complex stresses

Environmental Processes and Systems

- Predictive exposure assessment methodologies for existing and new organic and inorganic chemicals and nutrients

Water Quality Models

- Heavy metals, including mercury
- Persistent and highly volatile pesticides
- Nonpoint source loading models coupled to basin water quality models

Industrial Processes Program

- Identification and control of air pollution problems
- Hazardous waste disposal (closed-cycle systems)
- Water industrial processes

Monitoring and Technical Support Programs

- Alternate methods and products for measuring pollutants in industrial and municipal effluents
- Agencywide laboratory automation system (this technology is of particular importance to monitoring laboratories that must analyze large numbers of samples accurately to support enforcement actions).

List of Gap Areas

- Growth and concentration of population. (Although EPA does not formally adopt 10-year goals, its submission stated that "population aspects of the environment will be a major new area of research.")

National Aeronautics and Space Administration (NASA)

The basic research of NASA must be relevant to NASA mission objectives for aeronautical and space activities.

List of Priorities (short-term)

Physical Sciences

- Planets, comets, asteroids, stars, nebulae, galaxies, quasars, and other sources of radiation in all wave lengths, with emphasis upon gamma ray, x-ray, cosmic ray, visible sources, and UV and IR spectroscopy
- Interaction of the solar wind and the magnetosphere
- The interplanetary medium
- Nature of solar variability

Environmental Sciences (Planetary)

- Venus' atmosphere and gravitational character
- Jupiter, Saturn, and their environments by acquisition of imaging, fields and particles, and composition data
- Mars via continued analysis of data from Viking and other missions

Environmental Sciences (Earth)

- Remote sensing for identifying and monitoring pollutant species in the troposphere and water bodies, especially for all-weather and day and night conditions
- Remote sensing research on monitoring the physical parameters of the ocean surface using active and passive microwave radars
- Research into features of severe storms most readily identified by remote sensing technology
- Preliminary models of crustal inhomogeneities based on tectonophysics, magnetic field, and gravity field, etc.
- Composition and structure of the upper atmosphere

Life Sciences

- Physiological changes in man and other organisms in a gravity-free environment
- Search for extraterrestrial life

Engineering Sciences

- Fundamental knowledge of fluid mechanics and aerodynamics

- Basic understanding of noise- and pollution-generating processes resulting from aircraft operations
- Application of solid state chemistry and physics to improve the operational characteristics of electronic and optical materials
- Investigation of energy exchange processes among atoms, molecules, electrons, ions, and fields for use in energy conversion, lasers and their uses in science, and solar energy conversion
- Advance information and electronic sciences to provide improved data management at lowest possible cost
- Increase capability of engineering materials to withstand high temperatures to make possible development of efficient aircraft engines and space power systems
- Gain a basic understanding of fiber-matrix composite materials.

List of Priorities (long-term)

Physical Sciences

- Further surveys of the sky in the new wave lengths, which will identify objects and phenomena in the distant regions of the universe
- Study of these objects and phenomena at greater spectral and spatial resolutions
- Detailed understanding of the physical processes in the Sun-Earth system and within the Earth's complex magnetosphere-atmosphere system

Environmental Sciences (Planetary)

- Detailed studies of the terrestrial planets and bodies, relating their history and condition to those of the Earth
- Extending first-order knowledge to more of the outer planets and their satellites
- Reconnaissance of the smaller bodies in the solar system (comets and asteroids)

Environmental Sciences (Earth)

- Understanding and assessment of the contribution of individual climate elements to the climate picture
- Monitoring of major tectonic plate movement to an accuracy of a few centimeters per year

Life Sciences

- Use of the unique, gravity-free environment of space flight to further knowledge in medicine and biology by exploring basic physiological mechanisms in all living systems
- Search for extraterrestrial life and understanding the formation and existence of life in the universe

Engineering Sciences

- Technology base for new aeronautical concepts
- Efficient means to transmit energy in space
- Autonomous systems for space exploration
- Technology base for major breakthroughs in propulsion and space power systems
- Technology base for large-area systems for space missions
- Advance information science to include computer-human interactions, artificial intelligence, and establishment and implementation of the best use of computers.

List of Gap Areas

- Fundamental physical and chemical processes involved in the remote sensing of atmospheric and water constituents and pollutants
- Detection of strain buildup along extended faulted areas
- Increased activity in propagation research in new, higher frequency bands to provide opportunities for wider band future satellite communication links with reduced interference
- Research on artificial or machine intelligence
- Search for other planetary systems
- Search for extraterrestrial intelligence.

National Science Foundation (NSF)

The legislation that created NSF in 1950 declared that the first purpose of the act was "to promote the progress of science." By establishing the National Science Foundation, the U.S. Government set in motion a means to develop and encourage the pursuit of a national policy for the promotion of basic research and education in the

sciences and to initiate and support basic scientific research in the mathematical, physical, medical, biological, engineering, and other sciences. The commitment to the support of basic research and the promotion of the progress of science retain primacy in the Foundation's activities.

Within NSF three Directorates are primarily concerned with support of basic research: Mathematical and Physical Sciences and Engineering (MPE); Biological, Behavioral, and Social Sciences (BBS); and Astronomical, Atmospheric, Earth, and Ocean Sciences (AAEO). Other Directorates such as the Research Applications Directorate (now the Directorate of Applied Science and Research Applications), the Directorate for Science Education, and the Directorate for Scientific, Technological, and International Affairs also support some basic research.

AAEO

List of Priorities

Astronomical Sciences

- Development of improved detectors for existing telescopes
- Studies of high-energy processes in radio sources, quasars, pulsars, and x-ray sources
- Studies of early and late stages of stellar evolution
- Determination of the composition and physical conditions in the general interstellar medium
- Very long baseline interferometry
- Very large array telescope

Atmospheric Sciences (short-term)

- First GARP global experiment
- MONEX (monsoon experiment) analyses
- Mesocale meteorology
- Atmospheric chemistry
- International magnetosphere study
- Studies of solar activity and solar terrestrial relations

Atmospheric Sciences (long-term)

- Severe storm and mesoscale experiment
- Climate studies
- Magnetic cleft observatory to study the magnetic cusp (the magnetic cleft is a singular region of the magnetosphere at which the solar wind has direct access to Earth's atmosphere. It provides a unique environment for plasma physics studies and for studies of the impact of energy deposition on the Earth's atmosphere, which is believed to be of significance to global scale atmospheric behavior)

Earth Sciences

- Expanded ocean sediment coring program (such a drilling program may provide the scientific basis for the search for additional hydrocarbon energy sources)
- A continental drilling program, isotopic and high-pressure geochemistry related to the origin of ores
- Large-scale seismic reflection profiling to determine the fine structure of the crust and upper mantle

Ocean Sciences (short-term)

- Chemical, physical, biological, and geological processes at the deep-sea floor
- Recent evolution of the ocean basins and global climate
- Marine shallow water habitats
- Circulation, mixing, and transport processes in estuarine and continental shelf waters and adjacent boundary currents such as the Gulf Stream
- Structure and properties at the oceanic crust
- Physical oceanography of the equatorial Pacific
- Expanded and interrelated studies of marine organic materials, biochemical processes, and surface reactions on particulate matter

Ocean Sciences (long-term)

- Structure and function of open-sea biological communities emphasizing the role of nekton (free swimming aquatic animals)
- Physical processes involved in air-sea interactions with emphasis on large-scale interactions in the equatorial regions
- *In situ* marine chemical experimentation and manipulation
- Deep structure and geologic evolution of continental margins and the ocean basins
- Refinement of models of the general ocean circulation
- Determination of the driving forces for plate tectonics

Polar Sciences (short-term)

- Living resources and oceanography of the southern oceans

- Initiation of the West Antarctic Ice Stream Project (to determine whether the stream is stagnant or on the brink of a catastrophic collapse)

Polar Sciences (long-term)
- Continued emphasis on the southern oceans, as above
- Major geological drilling in the Dufek Mountains
- Ronne Ice Shelf Project (similar to the Ross Ice Shelf Project scheduled to close in FY 1979).

BBS

Physiology, Cellular Biology, and Molecular Biology
- Plant cell biology and physiology
- Mechanisms of photosynthesis and nitrogen fixation
- Plant and animal virology
- Somatic cell genetics
- Gene expression
- Structure and interaction of chromosomes and parts of cells
- Mechanisms of enzyme activity and protein structure
- Structure and motion of membranes, ribosomes, cells
- Research on large animals
- Advanced instrumentation for study of biological molecules and components of cells

Behavioral and Neural Sciences
- Analysis of human and animal behavior during development
- Genetic and hormonal determinants of behavior
- Research on human memory, learning, concept formation, and other cognitive processes
- Anthropological research collections
- Access to technologies for archeological dating

Social Sciences
- Economics
- Social/political processes in advanced industrial societies
- Sociology of the family
- Sociology of the complex organization
- Human modifications of environmental conditions

Environmental Biology
- Ecosystems studies
- Tropical and population biology
- Physiological ecology.

List of Gap Areas[13]
- Social sciences (large-scale data resources, collaborative efforts among the disciplines)
- Environmental biology (equipment for quantitative methodologies and analytical approaches).

MPE

List of Priorities[14]
- Turbulence (large-scale coherent structure, turbulent energy spectrum, turbulent motion controls phenomena such as the diffusion of momentum and the diffusion of scalar quantities such as temperature)
- Theory of nonlinear waves
- Oscillating chemical reactions
- Electronic and structural properties of liquids
- Transport and other properties of systems with two or more material phases
- Analysis of large, complex, man-made dynamic systems
- Relationships between mechanical properties of materials and their chemistry and internal structure (e.g., crack propagation, stress corrosion, hydrogen embrittlement)
- Added computational capability for theoretical chemistry
- Work on "intelligent systems"
- Dedicated instrumentation for computer research
- Fuller utilization of existing elementary particle accelerators.

Research Applications

List of Priorities (short-term)
- Earthquake studies
- Soil studies
- Identification and quantification of chemical pollutants

[13]NSF says funding levels in these areas are relatively low and scaled to individual project support.

[14]The MPE adds this caveat in listing the topics below: "Priorities in basic research are difficult, maybe even dangerous, to attempt to establish, given the unpredictable nature of future discoveries. About the best that can be done is to identify areas of emphasis based on the most promising research directions presently perceived."

- Conversion of lignocellulosic materials
- Nitrogen-fixing symbiotic systems
- Biophotolysis of water to hydrogen gas.

List of Gap Areas

- Bio-solar energy conversion
- The global CO_2 problem
- Environmental and other constraints that affect economic growth
- Drought management
- Structural design and engineering (the structural design process, machine design, human factors research, industrial engineering).

Smithsonian Institution

Research plans of the Smithsonian concentrate on the collection and exploration of basic information about and measurement of physical and cultural environments and man's effect upon them.

List of Priorities

- Archeological research in the New World
- Standardized collections of biological specimens
- Effects of land run-off on estuarine water quality
- Environmental effects of ultraviolet radiation
- Tropical forest regeneration
- Natural habitats critical in the preservation of endangered species
- Alternate food and energy sources
- Animal behavior and reproduction.

Veterans Administration (VA)

The mission of medical research in the VA is the improvement of health care, especially of veteran patients, through scientific efforts. A part of this mission is to provide a better understanding of the biological, chemical, physical, and behavioral phenomena underlying disease, disability, and health through a broad program of investigation of life processes.

List of Priorities

- Dedifferentiation/redifferentiation of neural tissue
- Biochemical and structural changes of aging
- Metabolic basis of alcoholism.

PART III

THE MISSION AGENCIES

Comparative Analysis and Historical Trends

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THE MISSION AGENCIES
Comparative Analysis and Historical Trends

Introduction

Although the sciences have been considered essential to the intellectual and pragmatic needs of this country since its beginning, the relationship between the Federal Government and the scientific community has developed slowly. During the Constitutional Convention, James Madison and Charles Pinckney attempted to make explicit provisions for Government support of science but they were thwarted by a coalition of two factions—those who thought that the power of Government to finance research was implicit and those who believed that such power was totally inappropriate.[1]

Because of the omission of explicit Constitutional authority for Government support, Congress often rejected proposals for Government involvement in science. In the early days, even Founding Fathers who advocated scientific investigation met with frustration. George Washington, for instance, asked unsuccessfully for a national university and for Government support of agricultural research. Over the years, it was often necessary to use subterfuge to obtain research funds. Even late in the 19th century, many proposals were passed only if they were attached to appropriation bills as riders.[2]

Despite congressional reluctance, the Federal Government gradually became more and more involved in the initiation and support of scientific research. In 1938, the Science Committee of the presidentially appointed National Resources Committee reported that the Government had conducted scientific investigation "from the earliest days. . .in order to establish a sound basis for its legislative and administrative activities," and that "government agencies were pioneers in carrying on research."[3] Even early projects such as the Coast Survey, various scientific expeditions, and the management of weights and measures were initiated and administered by Government agencies. Today scientific endeavor is supported by numerous mission agencies. This third part of the National Science Board's report attempts to trace briefly the history of each of the mission agencies, examining the development of support for basic research or the lack thereof in each case. First, however, it is useful to note three sets of events which had effects broader in scope than the work of individual agencies but which spurred their increasing involvement in research support. These were (1) wartime measures to stimulate scientific activity in pertinent areas, (2) Government surveys which, from time to time, assessed the role of science in Government and made recommendations, and (3) the Soviet Union's initial successful satellite launchings, the Sputniks, which catalyzed a great resurgence of national interest in and support for science.

[1]Dupree, A. Hunter, *Science in the Federal Government* (Belknap: Cambridge, 1957), pp. 4-5. Hereinafter referred to as Dupree.

[2]Ibid., p. 291.

[3]*Research—A National Resource*, Report of the Science Committee to the National Resources Committee (GPO: Washington, D.C., 1938), p. 3.

Wartime Measures

The National Academy of Sciences. During the Civil War, the Navy established a Permanent Commission which could answer the "questions of science and art upon which the Department may require information."[4] The commissioners and three other scientists recommended creation of the National Academy of Sciences (NAS), which was incorporated in 1863. Although the Permanent Commission was active throughout the war, the National Academy of Sciences made few concrete contributions except for correcting ships' compasses.[5]

The National Research Council. In the course of World War I, the National Research Council was created as a working arm of the NAS. The Council was highly effective during the war, as will be shown in the history of the Department of Defense; it continues to serve.

The Office of Scientific Research and Development. The threat of U. S. involvement in World War II and the poor state of U. S. preparedness led leading scientists to propose additional measures.[6] In 1941, the Office of Scientific Research and Development (OSRD) was created by Executive order. This Office directed most of the U. S. military research until after the war. Pleased with OSRD's success, Roosevelt wrote to its director, Vannevar Bush, that there was "no reason why the lessons to be found in this experiment cannot be profitably employed in times of peace."[7] One

[4]Gideon Welles, Navy Secretary, to Charles Henry Davis, February 11, 1863, in True, F.W., *A History of the First Half-Century of the National Academy of Sciences, 1863-1913* (Lord Baltimore Press: Baltimore, 1913), p. 1.

[5]Dupree, pp. 144-146; True, op. cit., pp. 216-217.

[6]Stewart, Irvin, *Organizing Scientific Research for War* (Little, Brown: Boston, 1948), p. 4. Hereinafter referred to as Stewart.

[7]President Franklin D. Roosevelt, letter to Dr. Bush, November 17, 1944.

of the direct results of this letter was the establishment of the National Science Foundation (NSF).

Government Surveys

The Allison Commission Survey, 1884-1886. The purpose of the Allison Commission was "to consider the present organization of the Signal Service, Geological Survey, Coast and Geodetic Survey and the Hydrographic Office."[8] The Commission, after rejecting an NAS recommendation to propose a Department of Science, made a less direct attempt to centralize science activity by suggesting that four bureaus be integrated into an existing agency. This recommendation met with intense controversy, and Congress took no immediate action.

The Committee on Organization of Government and Scientific Work Survey, 1903. Seventeen years after the Allison Commission recommended consolidation of scientific bureaus, the Committee on Organization concluded that, although duplication was not a problem, some consolidation of bureaus was probably desirable. It also recommended that research should be organized on the basis of pertinent problems, not according to the separate disciplines.[9]

The National Resources Committee Survey, 1938. This Committee probed the legal, social, and economic aspects of Government science and considered Government research in relation to research in universities and industry.[10] It was formed as part of a Government effort to provide depression relief for science in the civilian sector, but the Committee had no power and, at the onset of World War II, was superseded by the OSRD.

The Vannevar Bush Report, 1944-45. Vannevar Bush, with the help of qualified committees, produced a comprehensive report concerned with the natural sciences, including biology and medicine. The essence of his report is contained in the paragraph headings of his summary:

> Scientific progress is essential, For the war against disease, For our national security, For the public welfare; We must renew our scientific talent, Including those in uniform; The lid must be lifted; A program for action.[11]

Most significantly, Bush recommended enlightened Government support for scientific research and education, military research under a civilian-controlled organization, and the creation of a national research foundation.[12]

The President's Scientific Research Board Survey, 1947. This extensive survey led to a five-volume publication known as the "Steelman Report," which contained a national program, a Federal program, and recommendations for the administration of science, scientific manpower, and medical research. The Board urged such measures as increased annual expenditures for research and development, heavier emphasis on basic research and medical research, increased Government support of basic research in universities and nonprofit research institutions, establishment of the NSF, and Federal assistance to undergraduate and graduate students in the sciences and to universities for laboratory facilities and instruments.[13]

The Post-Sputnik Era

In October 1957, while the U. S. Navy was having difficulties with its modest but well publicized effort to put a small unmanned satellite into orbit, the U.S.S.R. orbited a satellite first, following it with a much larger one containing a live dog. Sputniks I and II shattered American complacency even though our relatively small Explorer was successfully orbited in January 1958 and a still smaller Vanguard in March 1958. The National Aeronautics and Space Administration (NASA) was established with good funding and high priority in an effort to catch up and pass the U.S.S.R. in space technology, and basic research profited from increased public interest. Then the U.S.S.R. orbited and recovered an astronaut before we did and there was another surge of public support for space science and for basic research. All federally funded basic research obligations quadrupled between 1958 and 1966. That this movement was broadly based is illustrated by the fact that it took only 2 years for the basic research obligations of the Department of Health, Education and Welfare (HEW) and of the NSF to double, with the Atomic Energy Commission (AEC) achieving this the following year and the Department of Agriculture a year later. Total Federal outlays related to research and development rose from 6 percent of all Federal outlays in FY 1958 to 12.6 percent in FY 1965 (and back down to 6 percent in FY 1975).[14]

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[8]Dupree, p. 215.

[9]Ibid., pp. 295-296.

[10]*Research - A National Resource*, op. cit.; Dupree, p. 360.

[11]Bush, V., *Science, the Endless Frontier: A Report to the President on a Program for Postwar Scientific Research* (GPO: Washington, D. C., 1945), pp. 1-4. Hereinafter referred to as Bush I.

[12]Bush I, pp. 26-34.

[13]Steelman, John R., *Science and Public Policy: A Program for the Nation* (GPO: Washington, D.C., 1947).

[14]National Science Foundation, *Federal Funds for Research, Development, and Other Scientific Activities* (NSF: Washington, D.C.), Vol. XXI, NSF 72-317, Table C-100; Vol. XXV, NSF 77-301, p. 4. Hereinafter referred to as *Federal Funds*, with appropriate volume and NSF publication numbers.

Conclusion

The wartime measures to harness science to the war effort were ineffective during the Civil War probably because the country lacked scientific and technical sophistication. They were fairly effective in World War I, a measure of how much our talents had improved. But after World War I the Government's research efforts faded rapidly, especially those in support of the military. World War II was a different story; the best scientists had to be mobilized to win the war and this lesson was not immediately forgotten. The Office of Naval Research (ONR), the AEC, the National Institutes of Health (NIH), and NSF brought about a new level of Government support for basic research. And when the effort lagged a little, the country was shaken by the news of Sputnik; science again became a major public concern and basic research support reached unprecedented levels.

The Government surveys provided information and suggestions on which action could be based. Some surveys recognized the need for a centralized research effort, but no action of consequence was taken until the Bush Report and the Steelman Report, both of which emphasized the importance of basic research to the national interest. The recommendations in these reports brought about the creation of NSF and must have given added impetus to the already existing agency programs in the interim.

Department of Defense

Army—Early History

The Army was the first agency to undertake a major basic research task for the Government, the Lewis and Clark Expedition of 1804-1806. When President Jefferson proposed an expedition to explore the Missouri River, he took vigorous steps to insure that the expedition would emphasize scientific investigation. He sent Captain Lewis to the American Philosophical Society in Philadelphia for special training in scientific observations, and provided instruments for the expedition. Furthermore, he issued detailed instructions on making astronomical observations, collecting natural history specimens, observing the Indians, and keeping records. The observations recorded by the expedition were not published in any form until 1814 nor reproduced until 1904. The specimens collected went to England to be described, but not until 1814. Although the findings of the expedition were significant, there was no scientific organization in the Government to make proper use of the data collected.[15]

The Corps of Engineers. Additionally, President Jefferson provided the Army with the first cadre of Government-trained scientists by creating a Corps of Engineers and a Military Academy, at West Point.[16] These measures provided the Army with officers schooled in mathematics and astronomy in order to make them competent surveyors and topographers. These specialists eventually became the Corps of Topological Engineers, and also served as explorers. For 50 years their expeditions not only helped achieve military and political goals but also advanced our knowledge in the natural sciences.

Although the Corps of Topological Engineers provided significant service to the Nation in peacetime, their specialty was not applicable to wartime concerns. Because of their separate goals, the Corps and the operating Army both found working together difficult.[17] The Corps of Engineers, which had separated from the Corps of Topological Engineers, did some basic research in hydraulics in connection with their peacetime civil duties, but apparently they did no research on wartime materiel (e.g., steel for rails). When the war ended the Engineers were reunited with the Topological Engineers and they continued civil pursuits.

Ordnance Department. Another group under the War Department that was entirely independent of the operating Army was the Ordnance Department, established in 1812.[18] In this Department, basic research was performed as part of the procurement function, and important advances in the design and founding of cast iron cannons were made as the result of studies in interior ballistics, the chemical and physical properties of iron, and the effect of grain size on the rate of combustion of gunpower.[19] However, the Department was often reluctant to foster and accept new ideas. For example, in a program based on the procurement of cast iron cannons there apparently was no research on steel cannons, which were gaining wide acceptance in Europe. Furthermore, the Department took 14 years to accept T. J. Rodman's improved cast iron cannon (but it eventually did so in 1859). After the Civil War, Ordnance was severely criticized by Congress for apparently re-

[15]Dupree, p. 28.

[16]Ibid., p. 29.

[17]Ibid., pp. 134-135.

[18]Reingold, Nathan, "Science and the United States Army," (unpublished monograph prepared for the National Science Foundation, c. 1955), pp. 4-5, 23. Hereinafter referred to as Reingold.

[19]Reingold, pp. 24-25; Dupree, pp. 126-127.

actionary attitudes responsible for sending the Army into the war with outdated arms and no adequate ordnance testing facilities.

Reacting positively to criticism, the Ordnance Department concentrated on the testing of ordnance and invented testing devices and methods. At the same time it reluctantly moved toward the use of steel. In 1873, progress was sufficient so that Congress began appropriating money for testing machinery, which led to the creation of a metallurgical research establishment at the Watertown Arsenal in Massachusetts.[20]

Medical Department. Another branch of the Army, the Army Medical Department, became an effective research organization during the Civil War under Surgeon General Hammond (although it had to be supplemented at first by a Sanitary Commission). The vast numbers of Civil War casualties due to wounds and disease presented a great challenge, but the Department kept detailed records and collected specimens for a medical museum, which became the foundation of the present Armed Forces Institute of Pathology. After the war it established what became the famous Army Medical Library.[21]

Army—Post-Civil War

After the Civil War ended, the Army Medical Department suffered from postwar demobilization to the point of severe shortages of personnel and drastic loss of funds. However, with the aid of the Museum and the Library and due to the personal drive of a few dedicated men like John Shaw Billings, J. J. Woodward, George M. Sternberg, and Walter Reed, Department researchers made significant advances, particularly in disease control.[22] They responded vigorously but without immediate success to the yellow fever epidemic of 1878.[23] Billings, an old sanitarian, was particularly influential, and Sternberg was one of those sent to Cuba to try to learn the cause of the disease. As the germ theory of disease became confirmed, Sternberg became known as the "Father of American Bacteriology," and Walter Reed also distinguished himself in this new field.[24] In 1893, Sternberg became Surgeon General and established the Army Medical School, where Walter Reed became professor of bacteriology. When the United States lost more men from typhoid than from battle injuries during the Spanish American War, the Army Medical Corps led the way in bringing this disease under control.[25] Then the Corps confirmed that the Aedes aegypti mosquito was the vector of yellow fever and brought this disease under control in Cuba. The control of yellow fever and a successful campaign against malaria made it possible to build the Panama Canal.[26]

In the meantime, First Lieutenant B.K. Ashford, M.C., discovered the relationship between hookworm and anemia and developed a practical treatment. The attacks on yellow fever and hookworm were continued by the Rockefeller Foundation and both diseases were virtually eliminated from the United States.[27] In 1910, Major C. R. Darnell, M.C., developed the use of anhydrous chlorine to purify drinking water, the method which with some modifications is used worldwide for water purification today.[28]

With an ongoing dynamic program of research and many years of distinguished accomplishments, the Army Medical Corps was ready for World War I. Under Surgeon General Gorgas the Corps became the dominant force in medical research. With the exception of one influenza epidemic, it made great strides in the prevention of disease. In fact, World War I was the first major war in history in which the mortality from communicable diseases was less than that from battle wounds.[29]

Signal Corps. Another Army unit that engaged in research was the Signal Corps. After the Civil War the Signal Service seemed doomed to failure because of its small size and discontinuous structure, but its aggressive leader, Brigadier General Albert Myer, formerly of the Medical Corps, succeeded in gaining national responsibility for meteorology from 1870-1890. The Service collected data by telegraph.[30] This responsibility and most of the personnel involved were transferred to Agriculture in 1890, and the Signal Service became the Signal Corps under A. W. Greely.[31] Greely revived two lines of research which had been neglected for 20 years, communications and aeronautics.[32] (Aeronautics will be discussed under the Air Force.) He stimulated research in electrical fire control equipment and advanced electrical communications, including wireless.[33] During World War

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[20]Reingold, p. 76.

[21]Dupree, p. 129.

[22]Ibid., pp. 256-257.

[23]Ibid., pp. 263-264.

[24]Engleman, R. D. and R. J. R. Joy, *Two Hundred Years of Military Medicine* (GPO: Washington, D.C., 1975), p. 11; Dupree, p. 264; Reingold, pp. 64-65.

[25]Dupree, p. 264; Reingold, p. 65.

[26]Engleman, op. cit., p. 15; Reingold, p. 65.

[27]Dupree, pp. 266-267; Engleman, op. cit., p. 13.

[28]Engleman, op. cit., p. 16.

[29]Ibid., p. 17.

[30]Reingold, pp. 39, 42-43.

[31]Ibid., p. 51; Dupree, p. 192.

[32]Reingold, p. 51.

[33]Ibid., pp. 52-54.

I, the Signal Corps was particularly aggressive in seeking scientific help. It persuaded Robert Millikin, the head of the Division of Physics, Mathematics, Astronomy and Geophysics in the newly formed National Research Council, to accept a commission in the Corps. He recruited scientists, supervised the revival of meteorological work, instituted a program of research on photography, and continued research on wireless and the detection of aircraft.[34]

Chemical Warfare Service. When chemical warfare was introduced during World War I, the Bureau of Mines developed defense measures against it and a Chemical Warfare Service was created in the War Department. Some original work was accomplished here in the final months of the war. This research contributed to the understanding of the effects of chemical weapons and to the development of defenses against them. New offensive chemical agents were also synthesized.[35]

Army—World War I to World War II

The biggest change in Army research between World Wars I and II was the development of a strong General Staff which had authority over the technical corps and the operating Army as well. This had the positive effect of tying development to the needs of the potential user, but it had a negative effect on research. Although basic and applied research in metallurgy continued at Watertown, and the Chemical Warfare Service continued research on a small scale at the Edgewood Arsenal, almost all research and development for the entire period was devoted to standardization, and contacts with scientists in the universities were extremely limited.[36] Vannevar Bush says of this period:

> It is truly remarkable that the Services were able to accomplish as much as they did in the face of the tremendous obstacles which beset them on every hand in the peacetime years. The fundamental difficulty, of course, lay in the attitude of the American people toward preparedness for war.[37]

Army—World War II

In 1940, when scientific mobilization began with the creation of the completely independent National Defense Research Committee (NDRC) to aid in the defense effort, the War Department began to expand research again. Moreover, during the Second World War, when funds flowed freely from Congress to the military, the Army was finally able to capitalize on the civilian research potential. In fact, the success of the wartime research changed the status of scientific research within the Army from a peripheral activity to a necessity central to military planning.[38]

Army research increased and improved during World War II, and one project the Army handled, although it did not initiate it, was the successful development of the atomic bomb, under the Manhattan District. However, the highlight of this period was the effectiveness of the NDRC and the OSRD. But the wartime scale of OSRD effort could not be maintained,[39] and at the end of 1944 it began self-demobilization, which was largely completed by January 1946.[40] The Deputy Director of OSRD wrote:

> If, unhappily, there should be another war, there should be no need for another OSRD. It will be needed only if there is a large deficit of military research such as existed in 1940.[41]

Thus the need for continuing military research was recognized. The Army's current policy on research is illustrative of the new emphasis on research that was fostered during World War II:

> To maintain a strong and progressive research core by conducting a broad and continuing program, including an adequate in-house capability. . . . [and to] Maintain effective contact between the Department of the Army and scientists. . . .[42]

Army—Post-World War II

Following the war most Army laboratories were conducting research programs in-house, only augmenting this work by contracting with outside laboratories. This situation continued, with increasing emphasis on basic research, until 1951, when the Chief of Ordnance, who was responsible for 60 percent of the Army's R&D program, centralized his contractual basic research program at Durham, N.C. In 1961, this office became the Army Research Office and assumed responsibility for all Army research. Basic research continued to grow until 1964, when the impact of the

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[34]Dupree, pp. 313-314; Reingold, pp. 95-96.

[35]Dupree, pp. 319-322; Reingold, pp. 106-108.

[36]Dupree, pp. 331-332; Reingold, pp. 110-117.

[37]Bush, Vannevar, *Endless Horizons* (Public Affairs Press: Washington, D.C., 1946), p. 83. Hereinafter referred to as Bush II.

[38]Reingold, p. 119.

[39]Bush, Vannevar, *Modern Arms and Free Men* (MIT Press: Cambridge, 1968), foreward. Hereinafter referred to as Bush III; Pizer, Vernon, *The United States Army* (Praeger: New York, 1967), pp. 25-26.

[40]Stewart, pp. 299-313.

[41]Ibid., p. 325.

[42]See Part I for a complete statement of Army research policy.

Vietnam war and later the Mansfield amendment caused a decrease in basic research to about half its previous level. Since 1974, this trend has reversed and the Army states that the target level of 50 percent in-house/50 percent contract has almost been reached.[43]

Army—Current Trends

The Army's estimated obligations for basic research in fiscal year 1977 are $40.1 million—$13.7 million in the life sciences, $2.8 million in psychology, $5.7 million in the physical sciences, $5.0 million in environmental sciences, $3.1 million in mathematics, $9.7 million in engineering, and $0.1 million in the social sciences.[44] It runs 32 Government-operated R&D laboratories/facilities. Contracts or grants are awarded by several Army organizations—the Army Research Institute for the Behavioral and Social Sciences, the Army Medical Research and Development Command, the Army Research Office, and in-house laboratories. Proposals for contracts or grants are reviewed by in-house scientific personnel and by outside scientific peers. In addition the Army supports a small amount of research in foreign countries.[45]

In summary, for the first half-century the Army conducted research which greatly benefited the civilian sector as well as prepared the military for a defensive war, which fortunately they never had to fight. Research to improve Army materiel was generally neglected, and, as a result, the Union Army was not able to take full advantage of the industrial superiority of the North. In the second half-century, Army research was relevant but, except for that of the Medical Department, inadequate. Hence, at the onset of World War I most Army technology was distinctly inferior to that of our European allies and enemies. From World War I to World II the research effort was small and the emphasis was on standardization. During World War II, the military benefited from the massive contributions of the NDRC and OSRD. Since World War II there has been a determined effort never again to be caught unprepared.

Air Force—Early History

The Air Force may be said to have had its genesis in the Army Topological Engineers, who tried unsuccessfully to make observation balloons of service to the Army during the Civil War. They passed the buck to the Quartermaster Corps, who in turn passed it to the Corps of Engineers, who tried to pass it to the Signal Service. When the Signal Service refused to accept the responsibility, the Army temporarily dropped aeronautics.[46]

After the Civil War the Signal Service was made responsible for aeronautics but continued to neglect it in favor of meteorology.[47] However, in 1890 the Signal Service lost meteorology research to the Weather Bureau and became the Signal Corps. At this time the Signal Corps revived investigation in aeronautics. By 1908 the Corps had experimented with observation balloons and contributed to the development of Langley's aerodrome, a dirigible, and an airplane. Until the formation of a separate Air Service in 1918, aviation received the major part of the research funds allotted to the Signal Corps. However, testimony before the Congress in 1913 revealed that whereas Germany had spent $28 million on aviation, and France $22 million, the U.S. had spent only $435,000. It was apparent that we were technically behind our European allies and our enemies, even at the end of World War I.[48]

During the 1920's, the Army General Staff wanted to concentrate on the standardization of materiel rather than on its improvement. When the Air Service became the Air Corps in 1926, they turned to the National Advisory Committee for Aeronautics (NACA) and the Bureau of Standards for basic research. Industry used the results of NACA's basic research, but the Air Corps did not get funds or authority from the General Staff to encourage rapid development through purchases of advanced aircraft.

Air Force—World War II

Alfred Goldberg summarized the situation as the United States entered World War II as follows:

> . . . the planes themselves were inferior. The Spitfire and the Hurricane of the RAF and the Messerschmitt 109 of the Luftwaffe could fly faster and higher than the latest model P-36 and carried more armament. The German attack bombers—the Junkers 87 Stuka and the Junkers 88—outclassed the A-17 in every respect. Only the B-17 was superior to the best British and German bombers of the time.[49]

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[43]Army communication to NSB staff, April 1977.

[44]*Federal Funds*, Vol. XXVI, NSF 77-317, Table C-34.

[45]Army communication to NSB staff, April 1977.

[46]Dupree, p. 128.

[47]Reingold, pp. 45-51.

[48]Ibid., p. 102, quoting from Terrett, *The Emergency*, p. 30.

[49]Goldberg, Alfred, *A History of the United States Air Force, 1907-1957* (D. Van Nostrand Co.: Princeton, 1957), p. 45.

However, the R&D activities at NACA were stepped up shortly before the war and a concentrated effort during the war finally produced aircraft superior to that of most competitors except for the German jet fighters, which fortunately did not become numerous before Germany was overrun.[50]

In the fall of 1944, General Arnold, Chief of Staff of the Army Air Forces (AAF), recognized that "the first essential of Air Power is preeminence in research," and he formally constituted the AAF Scientific Advisory Group, with Dr. Theodore von Karman as chairman. Although Vannevar Bush recommended to President Roosevelt that postwar military research be under civilian control, von Karman strongly and persuasively stated that the Air Force (separated from the Army since 1947) should not delegate its research needs to any other Federal agency. He warned that:

> . . . problems never have final or universal solutions, and only a constant and inquisitive attitude toward science and a ceaseless and swift adoption of new developments can maintain the security of this nation . . . .

It was this philosophy which prevailed.[51]

Air Force—Current Trends

Air Force basic research policy since late 1974 can be summarized as follows:

1. Research is a fundamentally important part of the overall Air Force research and development program and the preservation of the quality of that program is of utmost importance.
2. Research funding should be protected from undue competition from development and production programs.
3. The primary emphasis of Air Force research should be preservation and enhancement of extramural capability to provide insight into the basic science . . . .[52]

Estimated obligations for Air Force basic research in 1977 are $82.6 million—$19.6 million for physical sciences, $16.4 million for environmental sciences, $8.0 million for mathematics, and $32.5 million for engineering.[53] The Air Force operates 14 in-house R&D laboratories/facilities and 4 FFRDC's, and carries out an extensive extramural basic research program chiefly through grants to universities; but officials are concerned that proposed legislation will, if passed, force the Air Force to change means of support from grants to contracts. In the major in-house laboratories, about 7 percent of the research is basic.[54]

Navy—Early History

Although the Navy produced such innovative weapons as the Truculent Turtle, a manually powered submarine, during the Revolutionary War, and Demologos, a steam propelled warship in 1815, the Department's first significant basic research project was not commenced until 1836. In that year Secretary of War Poinsett selected Lt. Charles Wilkes to command the United States Exploring Expedition. He specified that the purpose of the expedition was to "extend the bounds of human knowledge." In the course of the 4-year expedition the naval officers were in charge of hydrography, mapping, and magnetic and astronomical observations; an outstanding team of civilian scientists conducted studies in ethnology, anthropology, zoology, geology, meteorology, and botany. Results came from Latin America, the Antarctic, the Central Pacific Islands, and the western coast of America. The report on the expedition was the culmination of the greatest scientific publishing program undertaken by the Government before the Civil War; some of the charts prepared from this report were still the best available in 1943 for military landings in the southwest Pacific.[55]

For comparison with astronomical and magnetic observations made on the expedition, Lt. James M. Gillis of the Navy's Depot of Charts and Instruments and William Cranch Bond of Dorchester, Mass., were requested to make corresponding observations at home. Bond became director of the Harvard Observatory and Gillis created an observatory at the Depot because it was needed for calibrating chronometers as well as to support the expedition. This became the Naval Observatory, which is still charged with determining time for the Nation. Of its creation, Dupree says:

> The Naval Observatory is the classic example of the surreptitious creation of a scientific institution by underlings in the executive branch of the government in the very shadow of congressional disapproval. No more hated proposal existed, and nowhere had more pains been taken to prevent the creation of a new agency. Yet

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[50]Craven, W. F. and J. L. Cole (eds.), *Army Air Forces in World War II*, Vol. III (Univ. of Chicago Press: Chicago, 1951), pp. 666, 739-740.

[51]Air Force communication to NSB staff, April 1977; the quotation is from the von Karman report, "Toward New Horizons," Washington, 1945.

[52]See Part I of this report for complete statement of Air Force basic research policy.

[53]*Federal Funds*, Vol. XXVI, NSF 77-317, Table C-34.

[54]Air Force contribution to Part I, April 1977.

[55]Dupree, pp. 56-61.

despite this vigilance the forces that required an observatory gained their ends.[56]

The Observatory became a very important center for hydrography and meteorology under Lt. Matthew Fontaine Maury, who took over in 1842. Maury collected the data from ships' logs to get a worldwide picture of meteorology, ocean currents, and other oceanography. His "Sailing Directions" made it possible for U.S. clipper ships to reduce time of passage by one-fourth to one-third. He largely ignored the Observatory's astronomical responsibilities, however. The U.S. Naval Astronomical Expedition to the Southern Hemisphere, under Lt. Gillis, was sent to Chile in 1849 to make measurements of planetary positions in order to determine the sun's parallax, but because Maury failed to take simultaneous measurements in Washington, the expedition's main purpose was not achieved. It did, however, collect other valuable data.[57]

Another significant naval expedition, the United States Surveying and Exploring Expedition, went to the Southwest Pacific in 1853, returning by way of the Arctic in 1855. Deep water bottom samples were taken and some useful hydrographic data were published, but there was no money for a complete report of the expedition.[58]

Until 1845, the Navy was severely handicapped by lack of a naval academy—relatively few naval officers were well educated (although Dr. Hassler trained some in the Coast Survey). However, the Washington Navy Yard seems to have been a center of some technical innovation. Probably for this reason the Congress chose the Navy to supervise the development of electric motors and an electric locomotive proposed by Charles Page, an examiner at the Patent Office, in 1849.[59] Dahlgren, a Hassler-trained officer, did extensive ordnance research at the Navy Yard. He developed a superior cast iron cannon with characteristic "pop-bottle" shape that matched the strength to the internal pressure curve.[60]

Although the Navy was innovative, sometimes management was not adequate to produce desired results. In 1842, for instance, the Navy was authorized to build the Stevens "battery." This was to be a fast, iron-clad, steam-driven ship with long guns for both shot and shell; however it appears that technical contract management was not adequate, for the battery was never completed, although half a million dollars had been spent by 1855.[61]

Navy—Civil War

The Navy may be said to have done enough crude experimentation to be intellectually ready when the Civil War broke out, but it had not done the research which would have enabled it to solve problems (e.g., to prevent boiler explosions or to manufacture steel cannons).

Because the Navy was intellectually ready, it was able to take several important steps early in the war. In 1861 it approved plans for three types of armored ships. One of these was John Ericson's *Monitor.* Dahlgren was left in direct command of the Department of Experiments with full support of the Washington Navy Yard. Steam engineering R&D was stepped up, and B.F. Isherwood was made head of a new Bureau of Steam Engineering in 1862. Thus a hastily built steam navy successfully blockaded the South.[62]

Dupree summarizes the research situation during the Civil War as follows:

> Thus the Navy in the Civil War came to terms with every important phase of the technological revolution that affected it. Under constant criticism from outside and riven by internal controversy, the department nevertheless managed to find officers well qualified to handle the new research technology and put them in administrative positions where they were able to act. In no important way did they further the naval revolution, but to keep pace with it was a major accomplishment which hinted at the government's potential ability to apply scientific procedures to technological problems.[63]

Navy—Post-Civil War

After the Civil War the Navy engaged in a variety of research endeavors. It continued its role in exploration, with emphasis on the Arctic. At the Naval Academy one graduate, A. A. Michelson, began his famous measurements of the velocity of light which eventually made him the first American Nobel laureate in science. At the Naval Observatory astronomy again assumed real importance under Gillis, and, in 1866, the work on winds and currents which Maury had originated was transferred to a new Hydrographic Office. Although it is no longer a leader in astronomy as it was in the 1890's, the Naval Observatory plays a

[56]Ibid., p. 62.

[57]Ibid., p. 97.

[58]Nourse, J.E., *American Exploration in the Ice Zones* (D. Lothrop & Co.: Boston, 1884).

[59]Dupree, p. 49.

[60]Ibid., pp. 123-124; Alden, Carrol S., *A Short History of the United States Navy* (J. B. Lippincott: Philadelphia, 1927), p. 260. Hereinafter referred to as Alden.

[61]Dupree, p. 123.

[62]Ibid., pp. 124-126.

[63]Ibid., p. 126.

continuing role in the preparation of the Nautical Almanac and as the national center for determination of time.[64] The Hydrographic Office did not continue Maury's work in oceanography, an activity which was not revived until recent years. It attempted a survey of the Pacific, but this was halted because continuing funds were not appropriated. This was one of the reasons why the Nation was without adequate charts for our operations in the Pacific campaign of World War II.[65]

For the period from 1864 to 1914, departmental histories available at the Naval Historical Center provide very little information on basic research activities which affected naval materiel. In fact, there is a dearth of histories of the U.S. naval shore establishment prior to the beginning of World War II. Dupree summarizes the situation prevailing up to 1914:

> Profound as (the) changes were for naval warfare, they seldom proceeded directly from scientific research on the part of the Navy Department, but rather were wholesale borrowings from abroad, especially from the British.[66]

This much is known: the Navy scrapped most of its Civil War steam fleet after the war,[67] and by 1881, only wooden unarmored ships remained, none of them fit for warfare.[68] Finally, in 1883, three steel cruisers were authorized, but our industry had to learn how to make suitable steel plates, a problem solved in England 7 years earlier. Therefore the larger castings and forgings for the armament had to be imported in 1885. In 1890, three coastal battleships were authorized and they formed the backbone of the Navy which prevailed over the Spanish fleet in 1898.[69]

During this period of rebirth, the Navy had the good fortune to produce one of the world's greatest naval architects, David W. Taylor, whose *Speed and Power of Ships,* published in 1910, is still a classic.

Most of the main battery guns and shells for the new naval ships were manufactured at the Washington Navy Yard, which was made the Navy's center for ordnance production in 1884 and transferred to the management of the Bureau of Ordnance (BuOrd) in 1886. This country was incapable of making large steel forgings suitable for gun tubes or armor prior to about 1890.

The Bureau of Ordnance, faced with this shortage, financed many experiments in the alloying and treatment of steel suitable for Navy purposes, and an impetus was given this industry which brought it to the foremost position among similar industries throughout the world.[70]

The U.S. Navy had no propulsion laboratories until the Engineering Experiment Station (EES), authorized in 1903, was opened in Annapolis "to test and determine the suitability of certain steam machinery for use in naval vessels."[71] This was followed by the Naval Boiler and Turbine Laboratory in Philadelphia a few years later. These were almost exclusively testing laboratories until World War I.

Radio communication was so potentially valuable to the Navy that it received special attention. To eliminate total reliance on industry for testing as well as research, the U.S. Naval Radio Telegraphic Laboratory was established in 1908; it utilized facilities at the National Bureau of Standards in Washington, D.C. In addition to testing, this laboratory conducted basic research on propagation and transmission of radio signals, and developed, for example, the Austin-Cohen formula for propagation over ionospheric paths. Basic research in physics was also involved in the development of improved circuits, measuring apparatus, and the vacuum tube. When war became imminent all these groups were augmented; in addition, the U.S. Naval Radio Laboratory in Great Lakes, Ill., under A. Hoyt Taylor, conducted basic research on such topics as propagation at very low frequencies (20 to 75 kHz). During the war several of these groups were combined under Dr. Taylor at the Naval Air Station in Anacostia, D.C., under the title U. S. Naval Aircraft Radio Laboratory (NARL). The research conducted in this laboratory produced few pertinent results during the war, but it became a nucleus in the formation of the Naval Research Laboratory (NRL).[72]

Navy—World War I

By 1914 the Navy had only small research programs in radio and in hydrodynamics. But in 1915,

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[64]Ibid., pp. 185-186.

[65]Ibid., p. 187.

[66]Ibid., p. 304.

[67]Ibid., p. 126.

[68]Alden, pp. 407-408.

[69]Ibid., pp. 410-411; Singer, Charles et al. (eds.), *A History of Technology,* Vol. V (Oxford University Press: London, 1958), p. 373.

[70]Peck, Taylor, *Round Shot to Rockets* (U.S. Naval Institute: Annapolis, 1949), pp. 184, 200. Hereinafter referred to as Peck.

[71]"Welcome to the U.S. Naval Engineering Experiment Station" (EES: Annapolis, c. 1964), p. 20.

[72]Gebhard, L.A., *Evolution of Naval Radio-Electronics and Contributions of the Naval Research Laboratory* (NRL: Washington, D.C., 1976), pp. 1-21. Hereinafter referred to as Gebhard; Taylor, A. Hoyt, *The First 25 years of the Naval Research Laboratory* (Dept. of the Navy: Washington, D.C., c.1948), p. 13. Hereinafter referred to as Taylor.

due to threatening German submarine warfare, Secretary of the Navy Daniels appointed a Naval Consulting Board under the chairmanship of Thomas A. Edison. The Board projected a very extensive national program but in 1915 this country did not have the scientific and technological base to sustain such an effort. As a first step to improve the situation, the Board proposed the creation of a naval research laboratory and succeeded in getting it authorized with a $1 million appropriation to start it. However, before the laboratory could be built, the United States entered the war. Research was done at existing naval facilities; the new laboratory, which later became NRL, was postponed until 1923.[73]

The Council of National Defense requested the National Research Council (NRC) to act as its department of research, and appointed the Naval Consulting Board as its board of inventions.[74] Reviewing new inventions became the major activity of the Board. Of 110,000 suggestions only 10 had enough merit for detailed examination and only one was produced. It was apparent that, "in time of total war, random ingenuity is no alternative to the problem approach by teams of highly trained men thoroughly aware of both scientific theory and the needs of the services."[75]

When the Naval Consulting Board and the NRC started independently to work on acoustic detection of submarines, even before we entered the war, almost immediately the Secretary of the Navy created a coordinating committee. Under the ensuing program, industry set up an experimental station at Nahant, Mass., and university scientists set up one at New London, Conn. Crude passive direction-finding equipment of several varieties came out of these groups.[76]

From the nature of these devices it does not appear that any basic research was involved, but the New London group was certainly capable of doing good basic research and did so later. The French and British meanwhile had developed active sonar, or "Asdic," with which an acoustic pulse was generated and its reflection from the target received on the antisubmarine vehicle.[77] This could give both direction and range and the submarine could not avoid it by merely shutting down its machinery. We copied this and began research aimed at improving it, but the results of the research were not effective until after the war.

In spite of immediate postwar economies, considerable enthusiasm for innovation remained and some of the high-quality scientific groups assembled during the war were not demobilized. Some members of the New London group under H.C. Hayes were relocated to the EES, where they did significant research on the transmission of acoustic energy through water, and on applications of the knowledge gained from this research. One product of their work was the development of a sonic depth finder in 1922.[78] This group joined the radio research group under A. Hoyt Taylor as the original scientific staff of NRL when it finally came into being in 1923.[79]

Dr. Taylor's group at Anacostia (NARL) continued to do important research in radio; for example, they experimented with radio frequency amplification and public broadcasting, discovered reflections of relatively high-frequency radio waves from ships (and beat phenomena resulting from such reflections), and found perturbations of low-frequency transmissions at night, which had immediate practical applications to radio direction finders and longer range applications to understanding the diurnal variations of the ionosphere.[80]

Navy—World War I-World War II

During the war BuOrd assembled a group at the Washington Navy Yard, which eventually became known as the Naval Ordnance Laboratory (NOL), and this became a source of scientific and engineering talent. By 1918, the ordnance engineers had accumulated fundamental knowledge of mechanics and metallurgy, and by 1919, this knowledge had been applied to the development of 5-inch radially expanded mono-block guns. BuOrd financed some of Goddard's rocket research from 1920-23, but only for specific applications.[81] As a result of the limitations imposed by the 1921 Washington Conference, naval ordnance then experienced hard times.[82]

The Bureau of Engineering (BuEng) did research on corrosion and its EES claimed credit for first recognizing corrosion fatigue of metals.[83] The Bureau sponsored a great deal of basic research at NRL. As NRL's traditional chief sponsors, BuEng sought to have the Laboratory placed under its cognizance and this was done in

[73]Dupree, pp. 306-307; Taylor, pp. 1-2.

[74]Dupree, p. 312.

[75]Ibid., pp. 307-308.

[76]Ibid., pp. 318-319.

[77]Hersey, J. B., "A Chronicle of Man's Use of Ocean Acoustics," *Oceanus* (20), No. 2, 1977, p. 12.

[78]U.S. Navy Marine Engineering Laboratory, *The MEL Story* (USNMEL: Annapolis, 1965), p. 7.

[79]Gebhard, p. 34; Taylor, p. 13.

[80]Gebhard, p. 24.

[81]Christman, A. B., *Sailors, Scientists, and Rockets* (Naval History Division: Washington, D.C., 1971).

[82]Peck, pp. 206, 219-221.

[83]U.S. Navy Marine Engineering Laboratory, op. cit., p. 7.

1931. It had full control until 1939, in spite of the 1932 recommendations of the Navy's General Board, which were, in part:

> (a) Naval research, of which the Naval Research Laboratory is an essential agent, is a necessary Naval activity and should be continued. (b) The activities of the Laboratory should be confined to research and primary or laboratory experimentation. Subsequent full scale experimentation, service test, and production should devolve upon the material bureaus. (c) The Office of the Chief of Naval Operations is best fitted to administer the Naval Research Laboratory . . . .[84]

In 1925 NRL collaborated with the Carnegie Institution of Washington in the first measurement of the height and layer structure of the ionosphere. This was done by measuring the time interval between transmission of a radio pulse and its reception after being reflected by the ionosphere.[85] This basic research coupled with aircraft reflection observations made in 1930 led to the development of continuous wave (CW) aircraft detection equipment. Continuation of this work led to effective radar, which was first installed on shipboard in 1938, and to many later radar developments.[86] Most of the Navy's advanced communication equipment of this period was developed at NRL; this work arose from and capitalized on basic research done by the various research groups within NRL.

In underwater acoustics the practitioners of active sonar found frequently baffling phenomena which required greatly improved knowledge of the ocean as a sound path. E. B. Stevenson made improved measurements of the velocity of sound in the ocean.[87] In 1937 NRL collaborated with Woods Hole Oceanographic Institution (WHOI) in a series of measurements made with the help of the USS *Semmes,* a destroyer specially outfitted as a research ship, and WHOI's *Atlantis.* The *Semmes* measured acoustic transmission and the *Atlantis* measured water temperature. Together, the measurements explained the mysterious "afternoon effect" as a bending downward of the acoustic beam by surface water which had been warmed during the day. Because this discovery was classified immediately, and remained classified until long after many others also had learned of it, R. L. Steinberger of NRL and Columbus Iselin of WHOI never received due credit.[88]

[84]Gebhard, pp. 34-35.

[85]Ibid., pp. 171-172.

[86]Ibid., p. 80.

[87]Communication from Dr. B. Hurdle, NRL, to NSB staff, June 1977.

[88]Hersey, op. cit., pp. 13-14.

In addition to research on underwater acoustics and radioelectronics, NRL did basic research in physical metallurgy, radiography, atmospheric electricity, crystallography, and physical optics.[89]

Navy—World War II

The BuOrd official World War II history describes a situation that prevailed through the 1930's:

> [The Bureau] . . . in early 1941 included 17 independent sections with only a nominal division organization. (Communication between sections was minimal.) . . . In practice, the chief problem proved to be that while research could be coordinated without special difficulties, it almost inevitably tended to be subordinated to other functions. Congress was not generous with appropriations during the peace years . . . but . . . the problem was less that money was not granted than that it was not requested or was diverted to other purposes.[90]

The destruction of the U.S. ships in the attack on Pearl Harbor was a catastrophic demonstration of the vulnerability of ships to aircraft attack. An overall assessment of the Navy's condition at the time is revealing. Antiaircraft armament was woefully inadequate. The little .50-caliber machine gun as well as the unreliable 1.1-inch and the antiquated 3-inch antiaircraft guns had to be replaced by 20mm Swiss Oerlikons and 40mm Swedish Bofors. The country's best antiaircraft gun was the 5″/38, which was a deterrent but didn't become fully effective until its shells were fitted with proximity fuses. (The fuse was developed by OSRD with Navy funds, using laboratory facilities at the Carnegie Institution of Washington and later at Johns Hopkins University.[91]) On December 7, 1941, the Navy had 20 CXAM radars, most of them already installed on ships.[92] It had tested landing craft and had recognized the superiority of the unconventional Higgins design, but didn't have landing ships. Torpedoes did not run at specified depth and their exploders frequently failed to fire. The main battery guns on destroyers and battleships were excellent. The carrier-based aircraft with which the United States entered the war, especially our torpedo planes and our fighter aircraft, were distinctly inferior to those of the Japanese in terms of both aircraft performance and the weapons they carried.

[89]Taylor, pp. 25-26.

[90]Rowland, LCDR and Lt. W. B. Boyd, *The U.S. Navy Bureau of Ordnance in World War II* (GPO: Washington, D.C., 1954), pp. 8, 18-26.

[91]Stewart, pp. 123-124.

[92]Gebhard, p. 183; Taylor, p. 47.

The effectiveness of the OSRD's mobilization of science was impressive, and the Navy recognized the opportunity which it had missed before the war. In his report to the President for fiscal year 1944, Secretary of the Navy Forrestal said, " . . . It follows, therefore, if we are to be scientifically prepared for war, that preparation must take place before, not after, the outbreak of hostilities." In May 1945 he signed a directive: ". . . there is hereby established, in the Office of the Secretary of the Navy, the Office of Research and Inventions. . . ."[93]

One year later this became the Office of Naval Research (ONR) under a naval officer with a civilian deputy and a naval deputy. Both naval officers were to be technical specialists, one a specialist in ships and the other in aircraft.

The act establishing ONR provided that the Naval Research Advisory Committee advise on its policies and programs.[94] Robert D. Conrad is credited with being the architect of ONR's early policy of supporting a very broad program of contract basic research because he saw the Navy's interests and requirements as being very broad. Although concern over accepting Government sponsorship of its research was felt initially in academia, this dissipated rapidly and a good working relationship developed.

> I may sum up ONR's contribution in this important field of administration by noting that, by the competence of its personnel, and by its imaginativeness, ONR established a new kind of relationship between government offices and laboratories and the scholarly community, in which both have worked together for the advancement of science and technology and the improvement of the Navy's capabilities for national defense.[95]

Navy—Current Trends

Estimated obligations for Navy basic research in 1977 are \$115.8 million—\$42.7 million in environmental sciences, \$29.9 million in physical sciences, \$17.2 million in engineering, \$12.9 million in life sciences, \$9.0 million in mathematics and computer sciences, \$2.7 million in psychology, and \$1.4 million in social sciences.

The Navy now operates 24 R&D laboratories/facilities and has two Government-Owned Contractor-Operated (GOCO) laboratories and one Federal Contract Research Center (FCRC—called an FFRDC by NSF), the Center for Naval Analyses. Fifteen of the R&D laboratories are under the Director of Naval Laboratories (DNL). These serve the systems commands which have replaced the materiel bureaus, and most of their work is development. Each of these laboratories receives relatively small funding for basic and applied research from one or more system commands and also from the DNL. Funds from the DNL are used at the laboratory director's discretion, their use being reported to the DNL at the end of the year. His evaluation of these reports is used in apportioning the following year's allocation. Funds from the system commands are more likely to have their use specified. The Naval Research Laboratory is under the Chief of Naval Research and has a much larger research program with a big basic research component.[96]

Summary

The Navy began its research with programs in exploration, astronomy, oceanography, and ordnance. These areas have been of long-term significance to the Navy, since it must be able to travel and fight anywhere on the world's oceans. Only ordnance research had much immediate use to the Navy in the Civil War. By World War I the U.S. had an outstanding fleet, using knowledge both from Europe and from some U.S. research related to ships and ordnance. The chief naval threat of the war, however, was the submarine and the U.S., lacking knowledge of the ocean as an acoustical path, was initially hampered in conducting antisubmarine warfare. An active research program applicable to countering this threat was not started until after the war began.

Between World Wars I and II, the U.S. neglected research in ordnance and aircraft and, consequently, at the start of World War II, our technology lagged behind that of the enemy in many respects. Neither the Army nor Navy was ready for the war which was to be fought.

> Historians may differ as to the reasons why with all its remarkable scientific advances the United States lagged so dangerously in the development of weapons, but none will deny the fact.[97] . . . It was apparent to a few key scientists in the spring of 1940 that the United States was in imminent danger of being forced into a war for which the country was pathetically unprepared from the standpoint of new

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[93]Tyler, C. L., "The Relations Between the Military Services and Science in the National Security Program," in Weyl, F. J. (ed.), *Research in the Service of National Purpose* (ONR: Washington, D.C., 1966), p. 4. Hereinafter referred to as Weyl.

[94]Weyl, pp. 3-4.

[95]John S. Foster, Jr., DDR&E, in Weyl, p. 11.

[96]Communications from Navy to NSB staff, April-July, 1977.

[97]Stewart, p. 3.

weapons.[98] We had, during the war, approximately thirty thousand men engaged in the innumerable teams of scientists and engineers who were working on new weapons and new medicine.[99] But the U.S. developed weapons and countermeasures. By the end of the war the United States had superior aircraft, the atomic bomb, rapid fire guns, versatile radar, influence fuses, and accurate torpedoes. ". . . It became clear beyond all doubt that scientific research is absolutely essential to national security."[100] The realization was that an active research program is fundamental to military preparedness. ". . . If we are to be scientifically prepared for war—preparations must take place before, not after, the outbreak of hostilities."[101]

Other Aspects of Department of Defense Research

The Director of Defense Research and Engineering (DDR&E) coordinates the research activities of all branches of DOD.[102] The total FY 1977 basic research obligations for DOD are estimated to be $274.7 million, of which $40.1 million is for the Army, $115.8 million is for the Navy, $82.6 million is for the Air Force, and $36.1 million is for the defense agencies. Most of this last $36.1 million is for the Defense Advanced Research Projects Agency (DARPA),[103] an agency reporting to the Secretary of Defense with staff supervision and scientific and technical policy direction from DDR&E. DARPA was originally created in 1958 as ARPA, an agency administratively under DDR&E. It was changed to its current form in 1972. Originally, it was the military counterpart of the National Aeronautics and Space Administration (NASA). ARPA was considered necessary to respond to the threat of the USSR's large military booster rockets. Later, the Saturn booster project was transferred to NASA, and most of ARPA's other space research was gradually transferred to the Air Force. ARPA then developed some long-range programs such as a series of interdisciplinary materials laboratories, which are now the responsibility of NSF. DARPA now primarily funds long-range, high-military potential research, but operates no laboratories of its own.

One in-house laboratory, the Armed Forces Radiobiology Research Institute (AFRRI) in Bethesda, Md., is an activity of the Defense Nuclear Agency (DNA), once known as the Armed Forces Special Weapons Project. The DNA comes under the Joint Chiefs of Staff, the head of the military component of DOD. DNA also supervises or otherwise participates in a great deal of research which comes under the budget of the Energy Research and Development Administration (ERDA), a means of giving the military a hand in nuclear weapons development while leaving the fiscal control vested in a civilian agency.[104] DOD also sponsors one FFRDC, the Institute for Defense Analyses.[105]

Department of Commerce

The history of the Department of Commerce goes back only to 1903, when the Department of Commerce and Labor was created. Some of its units currently involved in basic research are the Bureau of the Census, Economic Development Administration (EDA), Maritime Administration (MarAd), National Bureau of Standards (NBS), National Fire Prevention and Control Administration (NFPCA), National Oceanic and Atmospheric Administration (NOAA), and the Office of Telecommunications. Five components of Commerce estimate more than $1 million each for basic research in 1977—NOAA with $11.8 million, NBS with $6.5 million, NFPCA with $3.1 million, EDA with $1.7 million, and MarAd with $1.5 million.[106]

The Patent Office, which does no basic research today, was the first unit of the present Department of Commerce which engaged in direct interaction between the Federal Government and science. This occurred in the early days of this country when the Patent Office was the personal responsibility of the Secretary of State. Dupree invited attention to the anomalous situation which this caused:

> There is something sublime and pathetic in the spectacle of the Secretary of State (Thomas Jefferson) and a battery of professors from the University of Pennsylvania gathered around a distilling apparatus in the Secretary's Office to test the efficiency of a mixture supposed to make salt water fresh.[107]

In 1836, the Patent Office was placed under the first commissioner of patents, Henry Ellsworth, who was provided with a staff of scientifically competent examiners. Patent work was not basic research, but Commissioner Ellsworth also encouraged the collection of natural history speci-

[98] Ibid., p. 4.

[99] Bush II, p. 6.

[100] Bush I, p. 50.

[101] Secretary of the Navy Forrestal in his report to the President for fiscal year 1944.

[102] Borklund, Carl W., *The Department of Defense* (Praeger: New York, 1968), pp. 5-39.

[103] *Federal Funds*, Vol. XXVI, NSF 77-317, Table C-30.

[104] *United States Government Manual 1976/77* (GPO: Washington, D.C., 1976), p. 221.

[105] *Federal Funds*, Vol. XXV, Appendix B, p. 61.

[106] *Federal Funds*, Vol. XXVI, NSF 77-317, Table C-34.

[107] Dupree, p. 12.

mens as well as patent models, and he involved the Office in agriculture[108] (see also the Smithsonian Institution and the Department of Agriculture). The Patent Office moved to the Department of the Interior in 1849 and to Commerce in 1925.

NOAA—Origins

The largest basic research program in the Department of Commerce is that of the National Oceanic and Atmospheric Administration (NOAA). One of NOAA's current programs began in 1807, when the Congress authorized a general and comprehensive survey of the coast, employing the latest scientific methods brought to this country by Ferdinand Rudolph Hassler, a Swiss geodesist. He was equipped with a scientific library, some fine instruments, and a set of French standard weights and measures.[109] Initially, management of the Coast Survey was directly under the President, but the Treasury Department actually handled it for him and became the official sponsor. Field work didn't begin until 1816 and was interrupted from 1818 to 1832, when the Navy managed the work. Hassler insisted on doing the survey scientifically with astronomical observations, as opposed to the Navy's reliance on chronometers for the determination of longitude.[110] Alexander Dallas Bache took over from Hassler in 1843, and continued to use the scientific methods.[111] The Coast Survey became the Coast and Geodetic Survey in 1871 when Congress assigned it responsibility for the geodetic control of the interior. It was transferred to Commerce in 1965 as part of the Environmental Science Services Administration (ESSA). Its name was again changed to the National Ocean Survey when ESSA became part of NOAA in 1970.[112]

Another activity involved in basic research that recently became part of the Office of Ocean Engineering is the National Data Buoy Development Project, which originated in the Coast Guard in 1967. The goal of the project is to develop a system to provide continuous observations of the marine environment, taking data for all "agencies involved in understanding, predicting, or controlling the marine environment."[113]

Another part of NOAA which came from ESSA was the Weather Service. From 1890 to 1970 this had been the Weather Bureau and functioned within the Department of Agriculture until 1940, when it was transferred to Commerce. Prior to the formation of the Weather Bureau, other Federal agencies had collected meteorological data, notably the Land Office beginning in 1817, and later the Smithsonian and the Army Signal Service. However, the greatest need for research in meteorology was felt after World War I, when the rapid growth in aviation created the need for collection of weather information. Radio enormously increased our ability to collect and disseminate weather data. Airmass analysis opened a new dimension in U. S. meteorology in 1934. This was the result of basic discoveries made earlier in Europe as a result of World War I experience, but not recognized here until that time. The techniques were not officially adopted for another 4 years.[114]

The National Marine Fisheries Service, another office administered by NOAA, has origins going back to 1871. In that year Smithsonian Assistant Secretary Spencer Baird recommended to the Congress that it take steps to prevent undue depletion of food fishes of the seacoasts and lakes of the United States. He was made the first Commissioner of Fish and Fisheries, and almost immediately he began research at Woods Hole, Mass., on striped bass, bluefish, and other species. The first Federal fishery research laboratory was constructed there in 1884-1885.[115] Baird and his associates from the Smithsonian did basic research in marine biology and conducted applied research in support of the fishing industry. The Commission became independent in 1888 and remained so until it was placed in the newly created Department of Commerce and Labor in 1903. From 1939 to 1970 it functioned under various titles in the Department of the Interior, and then it became the National Marine Fisheries Service of NOAA. The Fishery Research Laboratory was joined at Woods Hole in 1888 by the Marine Biological Laboratory and in 1930-31 by the Woods Hole Oceanographic Institution; since then Woods Hole has become a world famous center for ocean science. These latter two institutions are privately operated with strong university connections, but a great deal of their research is funded by various agencies of the Government.

The Fisheries Service did basic research on the Alaska red salmon that enabled us to negotiate

[108]Ibid., pp. 47, 110-111.

[109]Ibid., p. 29.

[110]Ibid., pp. 31-33, 52-54; Popkin, Roy, *The Environmental Science Services Administration* (Praeger: New York, 1967), pp. 19-28.

[111]Dupree, pp. 55-56.

[112]*Annual Report of the Secretary of Commerce* (Bicentennial Edition) (GPO: Washington, D.C., 1976), p. 101.

[113]Ibid., p. 112.

[114]Ibid., pp. 105-108; Popkin, op. cit., p. 86; communication from NOAA to NSB staff, October 1977.

[115]Ibid., p. 109; Woods Hole Oceanographic Institution, "Questions and Answers" (WHOI: Woods Hole, Mass., 1969), p. 2.

successfully for its protection in the International Convention for the High Seas Fisheries of the North Pacific Ocean. In 1975 a comprehensive Atlantic bluefin tuna research study was designed and implemented.[116] There appears to be other basic research going on in this branch, although it is clear from the Secretary's annual report that its emphasis is on economics, conservation, the fishing business, and the amateur fisherman. Commerce reports no 1977 basic research in the life sciences.

NOAA—Current Trends

NOAA reports that all its basic research for 1977 is in the environmental sciences—oceanic and atmospheric.[117] "NOAA's research, with the exception of Sea Grants' applied research is conducted primarily in-house." The major in-house facilities for basic research in oceanography are the Atlantic Oceanographic and Meteorological Laboratory and the Pacific Marine Environmental Laboratory. NOAA's basic research in oceanography is less than 20 percent of that in meteorology. Nevertheless, NOAA does report significant recent results from programs in basic oceanic research.[118] In addition to its own research, NOAA provides valuable services to all oceanographers, and others with an interest in the sea, through the National Oceanographic Data Center and the National Oceanographic Instrumentation Center (both inherited from Navy) and through the above-mentioned Data Buoy Development Project.

An examination of the NOAA section in Part I reveals that atmospheric science receives the major emphasis in its basic research program. In the late 1940's the Weather Bureau established small in-house programs for research on basic cloud and precipitation physics, as well as on a number of other meteorological projects which represented the beginning of a fundamental atmospheric research program. In 1953, when a digital electronic computer became available, it began investigating the circulation of the atmosphere, and this work continues today at the Geophysical Fluid Dynamics Laboratory in Princeton, N. J. During the International Geophysical Year (IGY) (1957-58), the Weather Bureau began collaboration with NSF which led to the current program of Global Monitoring for Climatic Change. The need to eliminate air pollution and to predict severe storms led to the creation of the Air Resources Laboratory, the National Hurricane, and Experimental Laboratory, and the National Severe Storms Laboratory, all of which conduct programs that include both basic and applied research. The laboratories have studied such phenomena as atmospheric turbulence and diffusion and structure of severe storms such as hurricanes, tornadoes, and violent thunderstorms.[119]

In a transfer from NBS, ESSA received programs and personnel in telecommunications, space environment, and aeronomy research. Telecommunications is now a separate unit, not in NOAA, and the other programs which NOAA now has have been altered. Their previous focus was on the atmosphere as a transmission medium for electromagnetic radiation, but now the electromagnetic radiation is used as a tool to study the atmosphere with remote sensing techniques.[120] In newly formed laboratories the skills and techniques of these scientists are being used to probe the environment, especially to study the stratosphere, the upper atmosphere, and the space environment.[121]

In summary, NOAA has an active basic research program and finds this valuable in meeting the responsibilities of its mission. NOAA reported having $50.1 million in 1977 for research in the life sciences, none of it basic, and $59.9 million for research in environmental science, of which $11.8 million is for basic research.[122] The total lack of basic research in marine biology indicated by the above figures may reflect a particularly stringent interpretation of the definition somewhere in the system. In the environmental sciences NOAA's basic research program is considerably heavier in atmospheric than oceanic sciences, in spite of the strong emphasis on oceanic science in the Stratton Report[123] (which is credited with playing an important part in the creation of NOAA).[124]

NBS—Origins

The second largest basic research program in the Department of Commerce is that of the National Bureau of Standards (NBS), which has a $6.5 million basic research budget—$5.4 million allocated for physical sciences and $1.2 million for engineering.[125]

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[116] *Annual Report of the Secretary of Commerce*, op. cit., pp. 11, 122.

[117] *Federal Funds*, Vol. XXVI, NSF 77-317, Table C-34.

[118] NOAA communication to NSB staff, May 1977.

[119] Ibid.

[120] See Part I, NOAA section.

[121] NOAA communication to NSB staff, May 1977.

[122] *Federal Funds*, Vol. XXVI, NSF 77-317, Tables C-15 and C-34.

[123] Commission on Marine Science, Engineering and Resources, *Our Nation and the Sea* (GPO: Washington, D.C., 1969).

[124] *Annual Report of the Secretary of Commerce*, op. cit., p. 101.

[125] *Federal Funds*, Vol. XXVI, NSF 77-317, Table C-34.

Standards of weight and measure were originally provided for when the Constitution was written. The first effort to satisfy this requirement was made by Secretary of State Jefferson, but his proposals were turned down by the Congress in 1796.[126] No further steps were taken until 1836, when Dr. Hassler included standardization of weights and measures in the Coast Survey.[127] As late as 1886 the head of the office testified that, "the office of weights and measures at present is a very slight affair, I am sorry to say."[128] In fact, instruments needing careful calibration had to be sent abroad, usually to Germany.[129] Germany had created a complete establishment for such work in 1868, and England took initial steps as early as 1871. In the United States a bill establishing the National Bureau of Standards within the Treasury Department was passed in 1901. The Bureau was transferred to the Department of Commerce and Labor when that department was established in 1903. From the very beginning NBS has recognized that it must perform basic research of many kinds, including determination of physical constants and properties of materials.

The Bureau played an important role in World War I, working with industry and the Carnegie Institution to develop high-quality optical glass, and to redevelop optical instruments which had previously been German industrial secrets.[130] In the mid-to-late 1920's NBS peaked in influence under Commerce's aggressive secretary, Herbert Hoover.

> One of the ten points in his campaign against waste was the development of pure and applied scientific research as the foundation of genuine laborsaving devices, better processes, and sounder methods.[131]

The Bureau's research was drastically cut back during the depression.[132]

During World War II, the Bureau's expertise again was of great importance. It did important work on proximity fuses for bombs and rockets, a legacy of which is the Army's Harry Diamond Laboratory. Furthermore, it contributed to the atomic bomb project, primarily through studies of the purification of graphite and uranium and precise measurements of the properties of these and other materials. In addition, the Bureau continued studies of optical glass, because by the beginning of the war the U.S. had fallen behind Germany and Japan in the development of optics. Less well remembered perhaps is the Bureau's development of an air-launched cruise missile, fully automated, which was successfully used against enemy shipping in the Pacific. It was developed too late to have a major impact on the war, however.[133]

NBS—Current Trends

The research responsibilities of the Secretary of Commerce, as stated in the Bureau's enabling act, include such basic research as the determination of physical constants, the development of methods of chemical analysis, the study of extreme temperatures, the investigation of radiation, the study of atomic and molecular structure, metallurgical research, etc.[134] However, when the Science Policy Research Division of the Congressional Research Service reviewed the Bureau for the Subcommittee on Science, Research, and Development in 1971, it warned "that there are problems confronting the Bureau which, if left unattended, may result in difficulties not only for the Bureau, but for the Nation as a whole."[135] One of these problems is the recent tendency of the Congress to assign NBS specific short-range tasks without adequate funding, forcing the Bureau to reallocate resources from its primary mission in order to perform these newly assigned tasks. A potential problem aired in the 1971 review is that all of the Bureau's authority "comes to it by delegation from the Secretary. . . . Thus the responsibilities and powers of the Bureau and its director, in principle, are subject to change by the Secretary of Commerce as he may see fit."[136] In private discussions, various NBS staff members have expressed the fear that research classified as basic is more likely to be cut than that classified as applied. One cause of this classification problem has been the Mansfield amendment, which applied only to DOD but was considered by some management personnel to apply to other agencies, including NBS.

The effect of the constraints has been to reduce the Bureau's basic research, but a strong and suc-

[126]Dupree, p. 18.

[127]Ibid., p. 52.

[128]Testimony before the Allison Commission, March 1, 1886, quoted in Dupree, p. 272.

[129]Dupree, p. 272.

[130]Ibid., p. 322.

[131]Ibid., pp. 338-340, quoting from Secretary of Commerce, *Annual Report, 1926, p. 3.*

[132]Ibid., p. 346.

[133]Communication from Dr. Allen Astin, former Director NSB, to NSB staff, July 1977.

[134]U.S. Library of Congress, *National Bureau of Standards: Review of Its Organization and Operations* (GPO: Washington, D.C., 1971), pp. 125-128.

[135]Ibid., p. 1.

[136]Ibid., p. 115.

cessful program has remained (described in Part I). In 1953, the necessity for high-quality work was well defined for the Secretary of Commerce by an ad hoc committee: "The standards, the measurements, the test procedures must be the very best, the most accurate, the most reliable that can possibly be achieved at any given time, limited only by the state of the art at the time."[137]

NBS has excellent modern facilities in Gaithersburg, Md., and a much smaller laboratory in Boulder, Colo., on premises shared with NOAA and Telecommunications laboratories. Also in Boulder is the Joint Institute for Laboratory Astrophysics (JILA), an imaginative and highly successful operation run for the last 15 years in compliance with a Memorandum of Understanding between NBS and the University of Colorado. JILA is a small laboratory with about 30 to 40 scientists from NBS and from the University. (Its unique mode of governance was discussed in Part II, Chapter1.) This laboratory does research in physics and astrophysics and on new units and fundamental standards. It is funded by NBS and the University, but the high quality of the talent available there has brought funds to the University from ERDA, ARPA, and NSF.[138]

Economic Development Administration

EDA was established in 1965 by the Secretary of Commerce to carry out most of the provisions of the Public Works and Economic Development Act of 1965. For 1977, it estimates $1.7 million in obligations for basic research in economics.[139] This year EDA initiated a program of bringing in scholars for one-year periods, chiefly under the Intergovernmental Personnel Act, whereby payment of the scholar's salary is shared by his or her home university and EDA. This provides an instant small staff of highly qualified economists to study selected problems.[140]

National Fire Prevention and Control Administration

This Administration was established by the Federal Fire Prevention and Control Act of 1974. It is the lead agency for all fire prevention and control activities, but its own research focuses on inhabited buildings. The 1977 budget is estimated to be $3.1 million in obligations for basic research being performed at NBS. Most of this research appears to be in physical sciences and engineering. The $1.7 million extramural basic research program is principally administered through grants to universities. Work is apparently done in psychological sciences, physical sciences, engineering, and education, and it probably includes some interdisciplinary research (reported as "other sciences").[141]

Maritime Administration

The last of the major basic research sponsors in Commerce is MarAd, with estimated obligations of $1.4 million for 1977. The figures reported to NSF indicate that only 2 percent is intramural; the remainder is assigned to industry for research in engineering.[142] The 2 percent intramural must not include administrative costs for contract research because MarAd does some basic operations research at its Computer-Aided Operations Research Facility (CAORF). The Maritime Transportation Research Board (MTRB) of the NRC has noted that MarAd supported about $150,000 worth of relatively basic research through the Interagency Ship Structure Committee and MarAd has confirmed that this is probably just as basic as that contracted directly to industry.

Historically its work dates back to the Merchant Marine Act of 1936, which established a five-member Maritime Commission in the Department of Commerce. This Commission sponsored the construction of some relatively modern cargo ships, some of which became naval combat ships during World War II. The Maritime Commission was replaced by the Maritime Administration in 1950. The 1936 Act was inadequate for keeping up with advances in technology, and it was superseded by the Merchant Marine Act of 1970. The basic research program reported above was provided for in this act.

MarAd has one laboratory, the National Maritime Research Center in Kings Point, N.Y. Most of the work there is evaluation of the equipment and systems developed by the R&D program.[143]

[137] A report to the Secretary of Commerce by the Ad Hoc Committee for Evaluation of the Present Functions and Operations of the National Bureau of Standards, October 15, 1953, p. 4.

[138] Evaluative Panel of the National Research Council, "An Evaluative Report on the Joint Institute for Laboratory Astrophysics," in *An Evaluative Report on the Institute for Basic Standards, NBS, Fiscal Year 1976* (NAS: Washington, D.C., 1977), pp. 55-60.

[139] *Federal Funds*, Vol. XXVI, NSF 77-317, Tables C-30 and C-46.

[140] Communications from EDA to NSB staff, September 1977.

[141] *Federal Funds*, Vol. XXVI, NSF 77-317, Tables C-30 and C-34; and communication from NFPCA to NSB staff, September 1977.

[142] *Federal Funds*, Vol. XXVI, NSF 77-317, Tables C-30 and C-34.

[143] U.S. Department of Commerce, "Serving the Nation" (Commerce: Washington, D.C., 1975), amended to reflect subsequent closing of center at Galveston; informal communications between MarAd and MTRB and the NSB staff, October 1977.

The contract program is operated from MarAd headquarters in Washington, D. C.[144]

National Advisory Committee on Oceans and Atmosphere

The Department of Commerce uses a wide variety of advisory assistance including several groups from NAS/NRC. One advisory committee of considerable interest because of its broad scope is the National Advisory Committee on Oceans and Atmosphere (NACOA), established by the Congress in 1971. Its 25 members,

> who may not be full-time officers or employees of the United States, shall be appointed by the President and shall be drawn from State and local government, industry, science, and other appropriate areas.[145]

Commerce provides staff, information, personnel, and administrative services and assistance, but the Committee's purview is marine and atmospheric matters throughout the Federal Government. NOAA is one responsibility of the Committee, but the Secretary of Commerce has called upon it for guidance in other areas, such as ocean engineering. It reports annually to the President of the United States, the President of the Senate, and the Speaker of the House of Representatives by way of the Secretary of Commerce, who must forward the report within 90 days with his comments.

Department of Agriculture

Early History

When President George Washington requested Government support for agriculture, the Congress declined to approve, even with the option of approving without an appropriation.[146] About 1839, federally supported agricultural research began in the Patent Office under its first commissioner, Henry Ellsworth. He collected statistics, distributed seeds, and in 1841, he became a strong advocate of the application of chemistry to agriculture as taught by Liebig. Ellsworth's successors, however, were less aggressive, so demand grew for a Department of Agriculture and a system of agricultural schools,[147] both of which were established by Congress in 1862. The first commissioner, Isaac Newton, established a chemical laboratory and professorships in botany and entomology. By 1870, there were divisions of chemistry, horticulture, entomology, statistics, seeds, and botany, to which was added a division of microscopy. The Division of Botany was the custodian of the National Herbarium from 1867 until 1896, when it was transferred back to the Smithsonian.[148]

The new Department of Agriculture had serious troubles. First, it was embarrassed by its failure to solve the problem of Texas cattle fever. Second, an autocratic commissioner had thoroughly antagonized the Nation's botanists.[149] In addition, the Department was severely criticized in *Science*, and had such a poor reputation for solving problems that the Department of the Interior was called upon when there was a plague of locusts in the mid-1870's. In the 1880's continental Europe restricted imports of U. S. meat products because of infection that the Agriculture Department could not eradicate. Gradually the Department reorganized into problem-solving scientific bureaus.

Shortly after 1900 the Department of Agriculture turned from responding to problems to taking an active part in seeking them out.[150] This growth of scientific competence required university help, and Agriculture called upon the land-grant colleges by cooperating with the States which controlled them.

A Bureau of Animal Husbandry was created in 1884 and solved its first problem, pleuropneumonia, by 1890. With help from Cornell University and a much better understanding of the relation of germs to disease (based heavily on European research), Texas fever was curtailed by 1893. Its eradication required further study of the tick, which had been found to be the disease vector.[151]

The entomologists moved into the field to work on the gypsy moth and the boll weevil.

> By 1916 the metamorphosis of the Bureau of Entomology into a new scientific agency was virtually complete, and it was proving its worth so regularly that its position in the government was not only secure but taken for granted.[152]

In 1898 Congress authorized experimental importation of plants and seeds; this act led to a new generation of explorers. Studies of exotic plants and their indigenous soils and climates led to experiments in this country with such products

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144Communication from MarAd to NSB staff.

145Public Law 92-125, 92nd Congress, H.R. 2587, Aug. 16, 1971.

146Dupree, pp. 15-16; U.S. Dept. of Agriculture, *Century of Service*(GPO: Washington, D.C., 1963), pp. 2-3.

147Dupree, pp. 110-113; *Century of Service*, op. cit., pp. 5-6.

148Dupree, pp. 150-156.

149Ibid., pp. 154-156.

150Ibid., pp. 158-163.

151Ibid., pp. 164-166.

152Ibid., p. 163.

as soybeans, Smyrna figs, Sudan grass, and durum wheat.[153]

Many States were also active in agricultural research, and from the beginning the Department worked with them. Experiment stations were established to provide the land-grant colleges with facilities for research, and the Hatch Act of 1887 linked the Department to the States' operation of these semi-autonomous experiment stations.[154] Cabinet status for the Department came in 1889. For many years most of the men chosen as secretaries had had extensive land-grant college experience.[155]

By 1916 the Department of Agriculture had grown into an awesome organization. Dupree summarizes its status:

> . . .no other great economic interest in the United States could boast such a research establishment for the application of science either in or out of the government. . . . Indeed, no comparable agricultural research organization existed anywhere else in the world.[156]

Dupree also describes the administrative advancements in the Department of Agriculture:

> The Department of Agriculture became a laboratory experimenting on the nature of a scientific bureau, gradually perfecting a standard form adapted to its particular problem, its position within the government framework, and its need for communication with the world of science outside.[157]

The Bureau of Chemistry, for example, administered the Pure Food and Drug Act from 1906 to 1940. Similarly, the Bureau of Entomology established programs on the European corn-borer, the Japanese beetle, and the pink boll worm.[158] Shortly after the war, Agriculture entered the social sciences with the creation of the Bureau of Agricultural Economics in 1922. This change helped to bring about other bureaus, chiefly in the thirties.[159]

Edwin T. Meredith became Secretary in 1920 and he tried to increase the emphasis on research. He stated that "research is the foundation of agricultural progress. Without it most of our agricultural activities could not exist."[160] His efforts were thwarted by the postwar congressional economy drive and the recession of the early 1920's. However, in 1928, the McSweeney-McNary Act authorized a broad program of forest research for which 12 forest experiment stations were established.[161]

Agriculture—1930 - Present

The Great Depression of the 1930's and the New Deal had substantial impacts on Agriculture. Secretary Wallace was the most scientifically grounded member of the Roosevelt administration. He took an important step to promote research in the natural sciences in 1934, when he began building up a great central research institution in Beltsville, Md.[162] Overall research budgets improved after 1935; the Bankhead-Jones Act of that year provided additional annual funds for scientific, technical, and economic research, and for other research in basic agricultural problems. "In thus appropriating funds for basic research, in addition to funds for highly specific problems, Congress recognized that fundamental research may often be more practical than short-cut research."[163] To carry out the provisions of the law, the Department of Agriculture established nine regional laboratories, normally associating each with a land-grant college.[164] About this same time Agriculture also became heavily involved in conservation, following the great midwest dust storms.[165] Successes in the thirties included a vaccine against hog cholera and the introduction of some 50 improved varieties of wheat.[166]

Four more regional research laboratories were established as a consequence of the Agricultural Adjustment Act of 1938, which was concerned with the disposal of large agricultural surpluses. These laboratories were excellently adapted to serving the country during World War II. They invented a variety of products made from agricultural materials. (One such product was mass-produced penicillin.) In addition, they contributed to food production, aerial photography, and mapping techniques. Insect control research, which resulted in the 1940 development of aerosols, also proved valuable for military land operations during the war.[167]

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[153] Ibid., p. 168; *Century of Service*, op. cit., p. 46.

[154] Dupree, pp. 169-170; *Century of Service*, op. cit., p. 24.

[155] Dupree, p. 173.

[156] Ibid., p. 183.

[157] Ibid., pp. 289-290.

[158] *Century of Service*, op. cit., pp. 84-85.

[159] Dupree, pp. 335-336.

[160] Meredith, E. T., "My Year in the Department," *Country Gentleman*, 86 (9), quoted in *Century of Service*, op. cit., p. 100.

[161] *Century of Service*, op. cit., pp. 129, 236.

[162] Dupree, pp. 348-350, 365.

[163] Secretary of Agriculture, *Report for 1935*, p. 86; as quoted in Dupree, p. 364.

[164] Dupree, p. 365; *Century of Service*, op. cit., 226-227.

[165] Dupree, pp. 363-364.

[166] *Century of Service*, op. cit., p. 234.

[167] Ibid., p. 290.

Research continued after the war along conventional lines aimed at increased production, better strains of plants and animals, eradication of disease, control of pests, better utilization of farm and forest products, etc. Much of this research is basic, but problem-oriented. In 1957, Agriculture established its first pioneering research laboratory at Beltsville, defining pioneering research as:

> . . .not aimed at specific practical problems or objectives but rather at the advancement of science. . . . Such research will be undertaken to discover the principles underlying research areas and to develop theory which will greatly facilitate problem research as needs arise. It will be expected to build a foundation for the quick effective and economic solution of research problems.[168]

Sixteen pioneering research laboratories had been established by 1961.

Agriculture—Current Trends

The size and breadth of the Department of Agriculture's current program is amply demonstrated in Part I. Its estimates for basic research in FY 1977 are $194.0 million total, with $115.9 million for the Agricultural Research Service (ARS), $48.9 million for the Cooperative State Research Service (CSRS), $24.7 million for the Forest Service (FS), $3.9 million for the Economic Research Service (ERS), and less than a million for the Statistical Reporting Service.[169] Table 2 of the Agriculture section of Part I shows the breakdown of the total research, basic and applied, by scientific field. In spite of the breadth and size of the program, Agriculture has been criticized for inadequate research in human nutrition.[170]

ARS is organized into 4 regions and 26 areas with facilities at 149 locations, of which 2 are large animal disease centers, 4 are large regional Agricultural Adjustment Act laboratories, and 1 is the principal central laboratory at Beltsville. CSRS funds considerably less than half of the research at the 56 State Agricultural Experiment Stations, plus some at 29 schools of forestry, 16 land-grant colleges, and the Tuskegee Institute. ERS conducts its research in Washington, D.C., and at 70 other locations. FS has eight regional experiment stations, the Forest Products Laboratory, and the Institute of Tropical Forestry; in addition, some FS research scientists do research in the field—frequently on or near a university campus.

[168]Ibid., p. 392.

[169]*Federal Funds*, Vol. XXVI, NSF 77-317, Table C-30.

[170]"World Food and Nutrition Study: The Potential Contribution of Research," NRC Steering Committee Study on World Food and Nutrition (NAS: Washington, D.C., 1977), e.g., pp. 57-58.

The Smithsonian Institution

Origins

The history of the Smithsonian Institution is very complex. When Smithson died in 1829, he bequeathed about one-half million dollars "to the United States of America, to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men."[171] The bequest became effective in 1835, and the following year Congress finally authorized prosecution of the claim to the legacy, but only after considerable debate.[172] However, the fulfilling of the bequest was delayed until 1846 because of further debate. Some thought that the Smithsonian Institution should be a scientific institution with laboratories; others thought it should be a library, a museum, a university, or a normal school. Some even wanted to send the bequest back to England.

Amidst the confusion in Congress, some groups of science-oriented people attempted to get control of the bequest. The National Institute for the Promotion of Science, founded in 1840, was one of the most important of these groups. It was organized with elected officers but was tied to the Government, because the members of the President's Cabinet were designated as directors of the Institute. (It was given care of the collections from the Wilkes expedition by act of Congress in 1841, but because the first curator greatly damaged the collections, they were transferred to the Patent Office in 1843.)[173]

Creation—1846

In 1846, Congress created an establishment by the name of the "Smithsonian Institution," consisting of the President and Vice President of the United States, the Chief Justice, the members of the Cabinet, the Commissioner of the Patent Office, and the mayor of the city of Washington. It provided that the business of the Institution should be conducted by a board of regents composed of the Vice President, the Chief Justice, the mayor of the city of Washington, three members of the Senate, three members of the House of Representatives, together with six other persons,

[171]Will of James Smithson, quoted in Oehser, Paul H., *Sons of Science* (Shuman: New York, 1949), p. 11. Hereinafter referred to as Oehser I; also quoted in Oehser, Paul H., *The Smithsonian Institution* (Praeger: New York, 1970), p. 15. Hereinafter referred to as Oehser II.

[172]Oehser II, pp. 16-17.

[173]Dupree, Chapter IV; Oehser I, Chapter III; Oehser II, pp. 15-16.

other than members of Congress, two of whom shall be members of the National Institute and reside in Washington, the other four to be inhabitants of the States, no two of them from the same State.[174] The Chancellor of the Board is elected by its members and by custom is always the Chief Justice. Today, the mayor of Washington is no longer included, the National Institute has long been defunct, and the six other persons have become nine, two from Washington, D. C., and the other seven from different States. The Board of Regents also elects the Secretary of the Smithsonian, whose rank is equivalent to that of the secretary of a department and who also serves as secretary to the Board and to the Executive Committee of the Board.

Joseph Henry. The first Secretary of the Smithsonian Institution, Joseph Henry, was probably the most distinguished physical scientist in America at the time.[175] His position was further strengthened by the fact that he had submitted to the regents a plan for the operation of the Smithsonian before they elected him Secretary.[176] Henry's final "Programme of Organization" was adopted by the Board on December 13, 1847. As he had promised in earlier correspondence, Henry set "increase of knowledge" as the primary goal and "diffusion of knowledge among men" as the secondary goal.[177]

The Smithsonian Institution began as a small enterprise with an annual budget of only $30,000 (the interest on the endowment).[178] Joseph Henry continually struggled to orient the Institution and its funds toward his goal—the increase of knowledge. He desired that the Smithsonian's building be simple and economical, but Renwick's elaborate "Norman Castle" was built in spite of his objections.[179] Henry refused to accept collections until they could be properly cared for; however, by the time Congress finally insisted that the Smithsonian take over the Government collections, Henry had an assistant, Spencer F. Baird, who wanted them.[180] Although Henry wanted the Institution to emphasize research, Senator Choate, a long-term champion of the plan to make the Smithsonian a library, advocated a maximum emphasis on the library aspects of the act. Secretary Henry resisted, but the Board of Regents appointed an aggressive librarian, Charles Coffin Jewett, as Assistant Secretary and assigned half the annual budget to the library. After 1850 this half had to be shared with the museum, but in Henry's view it still represented too much of a diversion from research. In 1854 be persuaded the Board to terminate this arbitrary division. Jewett went over their heads, appealing personally to the Congress, and he was fired for doing so. Finally, in 1866, the Smithsonian Library was transferred and became the nucleus of the Library of Congress, although the Smithsonian retained title.[181]

Henry provided an early means for scientists to publish the results of independent research through "Smithsonian Contributions to Knowledge."[182] He began work in meteorology and developed a chain of observers, furnishing some with instruments. When this activity became too large, he happily transferred it to the Army Signal Service. He pursued his own studies in fuel oils (animal and vegetable oils in those days) and acoustics; this work led to cheaper oil for lighthouses and a siren fog-signaling system.[183]

Spencer Baird. When Henry died in 1878, Spencer Baird was elected Secretary and continued his own efforts—to make the Smithsonian a great museum, a great center for research on the collections, and an important agent for expeditions and surveys.[184] One of the subsequent surveys played an important role in the growth of the Smithsonian—a survey of the arid West by John Wesley Powell. Through Powell's influence, the appropriation bill enacted by the Congress on March 3, 1877, contained a provision for a new Bureau of American Ethnology (BAE) in the Smithsonian Institution, and Powell became its first director.[185] The BAE conducted 85 years of research on the Indians of North America[186] before it was merged in 1964 with the National Museum Department of Anthropology to form the Smithsonian Office of Anthropology (now the Department of Anthropology in the Museum of Natural History).

Samuel Langley. The third Secretary was Samuel Pierpont Langley, best remembered for his pioneering research in aeronautics and studies on flight of birds. Langley's background, however, was in astronomy, and he created the Astrophysical Laboratory, now the prestigious Smithsonian Astrophysical Observatory (SAO), which is the

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174 Excerpted from the act as quoted in Appendix C of Oehser II, and from the *Congressional Directory, 1977*, pp. 715-716.

175 Oehser II, p. 28; Dupree, pp. 80-81.

176 Oehser II, p. 28.

177 Oehser II, Appendix D, "Joseph Henry's Programme of Organization for the Smithsonian Institution."

178 Dupree, p. 83.

179 Washburn, Wilcomb E., "Joseph Henry's Conception of the Purpose of the Smithsonian Institution," in *A Cabinet of Curiosities* (Univ. of Va. Press: Charlottesville), pp. 116-119.

180 Washburn, Wilcomb E., "The Museum and Joseph Henry," *Curator* VIII (1965), No. 1, pp. 35-54.

181 Dupree, pp. 84-85; Oehser II, pp. 38-39.

182 Oehser I, pp. 42-43.

183 Ibid., p. 57.

184 Oehser II, p. 41.

185 Dupree, pp. 199-211.

186 Oehser II, p. 114.

major part of the Center for Astrophysics in Cambridge, Mass., operated jointly with Harvard University. Langley also promoted the National Zoological Park.

Charles Walcott. Charles Doolittle Walcott, who was the next Secretary, was an invertebrate paleontologist. While in office he continued his own research on trilobites; in addition he promoted aviation, continuing Langley's experimentation and helping to organize NACA.[187] Starting in 1915, Walcott sponsored some of Robert H. Goddard's early experiments with rockets through grants from the income of the Smithsonian's Hodgkins Fund.[188]

Charles Abbot. Charles Greely Abbot was another Secretary who not only did research but also promoted its growth within the Smithsonian. He did research all the time he was Secretary and continued long after, getting a patent in the field of solar energy after his one hundredth birthday. An earlier invention of his was the pyrheliometer, which was used worldwide to measure the intensity of incident sunlight.[189] For the Institution, he established a Division of Radiation and Organism, currently the Radiation Biology Laboratory in Rockville, Md.; this unit conducted fundamental research on the relation of solar radiation to the growth of plants.[190] In addition, Abbot participated in establishing permanent formal control of the Canal Zone Biological Area (Barro Colorado Island in Gatun Lake) in 1940. This has since become a total Smithsonian responsibility and it is now known as the Tropical Research Institute.[191]

Alexander Wetmore. No major additional research activities seem to have been added by the ornithologist, Secretary Alexander Wetmore, but he did obtain important building additions, as have his successors. Secretary **Leonard Carmichael,** a psychologist, did a great deal to enhance the Institution's programs in the history of science and the history of art; he also was responsible for the association of the SAO with Harvard. Under Secretary **S. Dillon Ripley,** another ornithologist, there have been several research-oriented additions. One is a Center for Shortlived Phenomena, a clearinghouse to alert interested scientists about such varied events as volcanic eruptions and earthquakes, fireballs, oil spills, fish kills, and sudden wild animal migrations. This has spun off as an independent operation and has been replaced for in-house scientists by SEAN, Scientific Event Alert Network, which concentrates on the natural phenomena. There has been some reorganization to pull together work in oceanography, limnology, and ecology. This effort included the creation of a laboratory on the western shore of Chesapeake Bay for cooperative research and education in ecology.

[187]Ibid., pp. 54-55.

[188]Ibid., pp. 58-59.

[189]Ibid., pp. 59-61.

[190]Ibid., pp. 112-122.

[191]Ibid., pp. 124-125.

Current Trends

Until 1858, when Congress appropriated $4,000 for the arrangement and care of the national collections, the only operating funds were the interest on the endowment;[192] as late as 1901 the endowment was still less than $1 million.[193] The last reported market value of the endowment and similar funds (September 1976) is $44.7 million, of which $12.7 million is for estuarine and coastal oceanographic research in Florida, $16.0 million is for the Freer Gallery of Art, $7.4 million is for other restricted uses, and $8.5 million is for unrestricted uses. The interest from both the latter two categories is spent largely for research. There are also grants and other bequests, amounting to almost $5 million in a recent 15-month period, a large portion of which are for research.[194] The Smithsonian has received many grants from the Research Corporation, a private foundation formed in 1912 with the help of Secretary Walcott. Although the Smithsonian has close ties with this foundation (traditionally the Secretary of the Institution is a member of the Corporation's board of directors), it is not the foundation's principal beneficiary.[195]

Estimated Federal obligations for basic research in FY 1977 for the Smithsonian amount to $30.6 million—$13.0 million for life sciences, $10.1 million for social sciences, $5.1 million for physical sciences, and $2.4 million for environmental sciences.[196] This is in addition to the research done with nonfederal funds.

The Smithsonian is actively carrying out its mission—to increase and diffuse knowledge. The popularity of its museums, its zoological park, the Smithsonian Associates, and the Smithsonian Magazine demonstrate continued success in diffusion, as does the volume of its scholarly publications and communications. The increase of knowledge is also proceeding on many fronts, including physical and cultural anthropology (not only of

[192]"Statement by the Secretary," (Smithsonian Institution: Washington, D.C., 1976), p. 9.

[193]Dupree, p. 284.

[194]"Statement by the Secretary," op. cit., p. 47, supplemented by direct communication between Smithsonian and NSB staffs, July 1977.

[195]Oehser II, pp. 204-205; "Science, Invention and Society," (Research Corporation: New York, 1971), pp. 2-6.

[196]*Federal Funds,* Vol. XXVI, NSF 77-317, Table C-34.

prehistoric and exotic people but also of modern civilized subjects), biology of a great variety of flora and fauna, ecosystems, paleobiology, mineral sciences, oceanography, history, archeology, conservation, etc. The Smithsonian's Tropical Research Institute on Barro Colorado Island publishes some 50 papers a year on the flora and fauna of the area.[197]

The Smithsonian Astrophysical Observatory is an important center for basic research. It is part of a larger center that is operated jointly with Harvard University. Much of the research at the headquarters in Cambridge, Mass., is in the field of x-ray astronomy; for this work the Observatory uses satellite data collectors. The first of these satellites, Uhuru, has collected a large amount of data of such interest that the third Uhuru atlas is claimed to have been the most quoted single reference in all scientific literature in one recent year.[198] The fourth atlas, published in 1977, contains some 200 x-ray sources, two of which are thought to be superclusters of galaxies in which there is evidence of an enormous mass of gas, giving rise to speculation that this may provide enough mass to give a cosmologically closed universe.

A new activity at SAO is the Langley-Abbot program, named in honor of the two secretaries who were astrophysicists. This will provide modest opportunities for visiting theorists to come to SAO and make use of the enormous store of data on the sun to aid them in their attempts to explain solar phenomena. The radio astronomy of the Center for Astrophysics is primarily a Harvard activity, but SAO is involved in the work at the Mt. Hopkins Observatory near Tucson, Ariz. Facilities here include a 10-meter telescope for gamma-ray astronomy and optical and infrared astronomical telescopes. Of particular significance is a new 4.7-meter optical telescope expected to be available in the spring of 1978. The reflector is made of many panels, all mounted on the same bore system but given mini-adjustments by a laser-activated servosystem, the first time this technique has been attempted on such a large scale for such short wave lengths.

The Department of the Interior

Early History

The Department of the Interior is the Nation's principal conservation agency. It is responsible for most of our nationally owned lands and natural resources, for American Indian reservation communities, and for people who live in island territories under United States administration.[199] Created in 1849 by act of Congress, it assembled several disparate organizations—the General Land Office transferred from Treasury, the Patent Office transferred from the State Department, the Bureau of Indian Affairs transferred from the War Department, and a new Pension Office established to take over certain functions from the War and Navy Departments. The Secretary of the Interior was given some other responsibilities in the District of Columbia and he was made responsible for the National Census.[200] Interior's research may be said to have had its foundations in the expeditions and surveys conducted earlier by the Army, and in the later State resource surveys.

The Land Office and the Census were severely criticized in 1865 for having "the most profound ignorance of everything connected with the subject" (of the management of mineral lands).[201] However, in 1867 they commissioned Ferdinand Hayden to make a geological survey of Nebraska. He expanded this year by year until it became the Geological and Geographical Survey of the Territories. He did some important work, collected a great deal of data, and published extensively; however, he did not really effectively serve the needs of the mining industry and the land-grant people. The survey cost over $600,000.[202]

There were concurrent surveys by the Army and by John Wesley Powell. Professor Powell and his students first began exploring the Colorado Rockies under University of Illinois auspices, but with authority from the Army to draw rations for his party in the field. In 1868 and 1869 he did his famous work on the Grand Canyon with the same sort of support, but with specific congressional approval. In 1870, he conducted the Geographical and Topological Survey of the Colorado River of the West; this survey was funded by Congress, ostensibly through the Department of the Interior, but, due to a mixup, the first appropriation for it was given to the Smithsonian. In 1874, it became the Geographical and Geological Survey of the Rocky Mountain Region, under the Department of the Interior. In 1878, the excellent geological work of Powell's staff, Powell's own important work on the Indians, and his irrigation studies were published in his "Report on the Lands of

[197]Oehser II, pp. 124-126; *Smithsonian Year—1975*(Smithsonian Institution Press: Washington, D.C., 1975), pp. 448-450.

[198]Dr. Riccardo Giacconi, SAO, communication to NSB staff, January 1977.

[199]*United States Government Manual 1976/77*, op. cit., p. 292.

[200]Department of the Interior, *America 200*, Conservation Yearbook II (GPO: Washington, D.C., 1976).

[201]Whitney, J. D., Director of California State Survey, quoted in Dupree, p. 197.

[202]Dupree, pp. 198-199.

the Arid Region of the United States. . . . "[203] To add to the multiplicity of surveys of the West, the demonstrably efficient and scientific Coast Survey became the Coast and Geodetic Survey in 1878.[204]

USGS—Early History

The U. S. Geological Survey (USGS) was established on March 3, 1879, when legislation, based on the recommendations of the National Academy of Sciences and passed by the House but not by the Senate, was transferred from a bill that was stalled because of civil rights legislation to another bill which was passed in the closing hours of the 45th Congress. Surveys previously conducted under the War Department by Wheeler and under the Interior Department by Hayden and Powell were discontinued (but provision was made for the continuation of Powell's work in ethnology under the Smithsonian Institution).[205] Clarence King became the first director of the Geological Survey and planned a program emphasizing research in mineral deposits. In 1881, he was succeeded by Powell, who continued his ethnologic work for the Smithsonian from his Geological Survey office. Powell expanded the level of activity of the Survey by bringing in excellent scientists and allowing them to plan their own research. He employed college professors for part of the year and persuaded O. C. Marsh to become the Survey's vertebrate paleontologist with permission to work out of Yale. A very important series of monographs on vertebrate paleontology resulted. Powell also set up a chemical laboratory in the Survey's Washington quarters following a precedent established in Denver and San Francisco under King.[206]

In 1888, Congress mandated the Department of the Interior to examine areas requiring irrigation for agriculture; they provided funds for investigating the extent to which the arid regions could be redeemed by irrigation, the segregation of irrigable lands, and the selection of sites for reservoirs and other hydraulic works. To prevent speculators from obtaining the land, a proviso was added that all lands designated for reservoirs, etc., be reserved and not subject to entry or settlement unless the President opened them to settlement under the Homestead Law. The exact meaning of the reservation clause became an issue, and the Attorney General ruled that all lands that might possibly come under the 1888 law were reserved; in fact, the entire arid region was closed to entry. A storm of protest arose and the entire irrigation survey was wiped out in 1890. Two years later, basic research was attacked in the House and a coalition of Senators led by those who felt Powell's approach to the irrigation problem was wrong voted to severely cut Survey funds. Powell resigned as Director in 1894, but continued his ethnologic work for the Smithsonian, and C. D. Walcott, the Survey's first paleontologist, became Director.[207]

Under Walcott, there was a gradual restoration of the research program in economic geology. One of the first accomplishments of the Walcott regime was authorization for the Survey to gauge streams and determine the water supply of the United States, thus providing for research in water resources. Skillful management of this program aided in the passage of the Reclamation Law in 1902 and resulted in the assignment of the reclamation program to the Survey. In 1907, the Reclamation Service became an independent agency, but the Survey continued the research in water resources.[208] (Responsibility for water resources is now shared by the Survey and the Office of Water Research and Technology, established in the Secretary's Office in 1964.)

In 1904, the Survey began a program of determining the physical and chemical properties of coal, and in 1905, of the properties of structural materials. In 1908, the Survey began research relating to mine safety, and in 1910, the Bureau of Mines was established to continue the work of mine safety and fuel testing; the testing of structural materials was transferred to the National Bureau of Standards. By the beginning of the 20th century, the Survey had attained such an excellent reputation that its scientists were called on to aid other countries in developing their mineral and water resources and mapping programs. The Philippines and some Caribbean countries were given assistance of this kind immediately after the Spanish-American War. In 1907, Walcott's last year as Director, the Survey's total funds were $1.9 million; $1.8 million was directly appropriated, of which $350,000 was for fuel and structural materials testing, $350,000 for topographic mapping, $365,000 for geologic and mineral resources programs, $150,000 for water resources, and $20,000 for chemistry and physics.[209]

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[203] Ibid., pp. 199-200; *America 200*, op. cit., p. 79.

[204] Dupree, pp. 202-203.

[205] *The U.S. Geological Survey: Its History, Activities, and Organization*, Service Monograph No. 1 (Institute for Government Research: New York, 1918), pp. 6-9; Dupree, pp. 204, 209.

[206] USGS communication to NSB staff, December 1977.

[207] Rabbitt, M.C., *A Brief History of the U.S. Geological Survey* (GPO: Washington, D.C., 1974), pp. 9-11.

[208] Ibid., pp. 11-14.

[209] *U. S. Geological Survey 28th Annual Report, Fiscal Year 1907.*

Under George Otis Smith, Director of the Survey from 1907 to 1930, the major emphasis was on conservation and land management. A program of research in fundamental geological science was funded in 1930 but was discontinued after 3 years because of the depression. Strategic minerals investigations, which had been a significant contribution during World War I, were again funded in 1938.

USGS—Current Trends

Since World War II, all programs of the Geological Survey have been greatly expanded. In 1952, the Survey reported obligations for basic research of $4.9 million, all in physical sciences.[210] By 1963, this had grown to $15.6 million, excluding topographic mapping and stream gauging. All of this except $250,000 was intramural, all in the physical sciences (which in that reference included engineering and mathematics) except for $246,000 in the biological sciences.[211] For 1977, the estimates are $106.4 million, with $98.5 million in environmental sciences, $6.9 million in physical sciences, and $1.1 million in mathematics. Most of this research is intramural but $4.0 million of it is done in universities and $227,000 in industry.[212] USGS intramural research is performed at the headquarters in Reston, Va., at the Center for Astrogeology in Flagstaff, Ariz., and at two regional centers in Denver, Colo., and Menlo Park, Calif. All of these are Government-operated.

Bureau of Reclamation

The Reclamation Service was separated from the USGS in 1907, becoming the Bureau of Reclamation in 1923. The only mention of research in the monograph describing Reclamation in 1919 referred to the action of alkali on concrete.[213] The Bureau still does very little basic research; only $70,000 is estimated for it in 1977, all in engineering.[214]

Bureau of Mines

The Bureau of Mines separated from the USGS in 1910, and its early activities included research on several topics in order to carry out its responsibilities in the mining field. This research addressed such topics as the prevention of mining accidents, mining, mineral technology, metallurgy, and fuels.[215] Its mission briefly included testing structural materials but this function was transferred to NBS in 1913. In 1915 the Bureau became active in nonferrous metals research, and Congress provided for 10 regional experiment stations. These developed into regional laboratories, which concentrated on local problems. In 1917, when the demand for radium was great, the Bureau of Mines established a cooperative program with the National Radium Institute to make the Institute's knowledge on radium available.[216] During World War I the Bureau conducted research on the separation of helium from natural gas, on the storage of helium, on nitrogen fixation, and on defense against gas warfare.[217]

In 1922, the Bureau of Mines had a total operating budget of $1.5 million, including $200,000 for mining experiment stations, $50,000 for operating the Pittsburgh laboratories, $160,000 for research in mining and mineral technology, and $278,000 for research on solid fuels, petroleum, and natural gas.[218] In 1952, reported obligations for basic research were $2.5 million, all in the physical sciences.[219] In 1963, the basic research budget was $3.4 million, all for work in the physical sciences, and of which only $4,000 was extramural.[220] The estimates for basic research in 1977 are down to $800,000—$680,000 in the physical sciences and $120,000 in engineering, all of it intramural. One reason for this decrease is that five laboratories were transferred to ERDA in 1975.

U.S. Fish and Wildlife Service

As early as 1850, Connecticut passed a law protecting insectivorous birds.[221] In 1885 Congress appropriated $5,000 for research in economic ornithology to be done under Agriculture's Division of Entomology, and the next year a separate division was established for economic ornithology and mammalogy. In 1905 the Biological Survey was moved out of this division to become a separate bureau. This bureau and the Department of Commerce's Bureau of Fisheries (formerly the Fish Commission) were transferred to the Department of the Interior in 1939 and became a new

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210 *Federal Funds*, Vol. II, p. 32.

211 *Federal Funds*, Vol. XIII, NSF 65-13, pp. 146,150.

212 *Federal Funds*, Vol. XXVI, NSF 77-317, Tables C-34 and C-30.

213 *The U.S. Reclamation Service: Its History, Activities, and Organization*, Service Monograph No. 2 (Institute for Government Research: New York, 1919), p. 99.

214 *Federal Funds*, Vol. XXVI, NSF 77-317, Table C-34.

215 Powell, F.W., *The Bureau of Mines: Its History, Activities, and Organization*, Service Monograph No. 3 (Institute for Government Research: New York, 1922), p. 71.

216 Ibid., pp. 20-21.

217 Ibid., p. 36.

218 Ibid., pp. 143-144.

219 *Federal Funds*, Vol. II, p. 31.

220 *Federal Funds*, Vol. XIII, NSF 65-13, pp. 146, 150.

221 Cameron, Jenks, *The Bureau of the Biological Survey: Its History, Activities, and Organization*, Service Monograph No. 54 (Institute for Government Research: Baltimore, 1929), p. 12.

Fish and Wildlife Service. In 1956, work was divided between a Bureau of Commercial Fisheries (since transferred back to Commerce) and a Bureau of Sport Fisheries and Wildlife, since renamed the United States Fish and Wildlife Service.[222]

In 1928 the Bureau of the Biological Survey had a budget of about $1.0 million; most of this allocation supported research on wild animals and their habitat.[223] In 1952 the Fish and Wildlife Service of the Department of the Interior had only $469,000 designated for basic research, all in the life sciences.[224] In 1963 the budget was up to $1.5 million, all for research in the biological sciences and all intramural except for $402,000, for which the performers were neither profit nor nonprofit organizations—presumably State and local governments.[225] Obligations for basic research in 1977 are reported as $10.1 million, of which $150,000 goes to State and local governments, $900,000 to universities and colleges, $250,000 to industry, leaving $8.8 million for intramural research. All research supported is done in the life sciences.[226] The Service operates a headquarters in Washington, D. C., 7 regional offices, more than 350 national wildlife refuges, 35 fish and wildlife research stations and laboratories, cooperative research units at 45 universities, and nearly 100 fish hatcheries.

Office of Water Research and Technology

The Office of Water Research and Technology (OWRT) superseded the Office of Saline Water to carry out that office's functions and also to fulfill the new responsibilities vested in the Secretary by the Water Resources Research Act of 1964. OWRT is responsible for a cooperative Federal-State university program on water resources and for its own research program directed toward solving or mitigating water problems. In 1963, the Office of Saline Water conducted a $2.6 million extramural basic research program, of which $1.4 million was spent on research performed by profit organizations, $0.5 million by universities, $0.5 million by other nonprofit organizations, and $200,000 by foreign organizations. Of these obligations for basic research, $1.2 million were for research in the physical sciences and $1.4 million in engineering sciences.[227] In 1977, OWRT estimates $3.5 million for basic research, of which $530,000 is intramural; $395,000 is for research performed by industry, $2.5 million by universities, and $15,000 by State and local governments.[228]

National Park Service

The remaining component of the Department of the Interior with a significant basic research program is the National Park Service. The first national park was Yellowstone Park, established in 1872 as "a pleasuring ground for the benefit and enjoyment of the people." The bill was supported in Congress because of Yellowstone's exotic geological features. The Department of the Interior was given the responsibility of protecting the the park's wildlife and its geologic treasures, but failed to do so because there was no legislation under which violations could be punished until 1894.[229] President Theodore Roosevelt took action under the Antiquities Act of 1906 to put aside 1.4 million acres as national monuments, but the National Park Service did not come into being as such until 1916.[230] The act establishing the Service enjoined it to retain the national parks in their natural condition in perpetuity while making them available to the public.

Assistant Secretary Stephen Mather is credited with the initiative which brought the Service into being, and he became its first director. He was wholly dedicated to the Park Service but he and his early successors seem not to have recognized the need for basic research, which started only after World War II. Since then it has been 1.5 to 2 percent of the total budget, although the research staff of the Service believes it should be 7 to 8 percent.[231] Its budgeting process is such that research competes with operations for dollars.[232] In 1952, the basic research obligations of the Park Service totaled $371,000—$330,000 supporting research in the social sciences, $30,000 in the life sciences, and $11,000 in the physical sciences.[233] By 1963, these funds had grown to a total budget of $1.9 million; $1.1 million of this amount was intramural; $329,000 was for research performed by educational institutions, $427,000 by other nonprofit organizations, and $49,000 by State and local governments. Virtually all funds supported

[222]Ibid., pp. 21-27.

[223]Ibid., pp. 214-215.

[224]*Federal Funds*, Vol. II, p. 32.

[225]*Federal Funds, Vol. XII, NSF 65-13, pp. 146, 160.*

[226]*Federal Funds*, Vol. XXVI, NSF 77-317 Tables C-30 and C-34.

[227]*Federal Funds, Vol. XII, NSF 65-13, pp. 146, 150.*

[228]*Federal Funds*, Vol. XXVI, NSF 77-317, Table C-30.

[229]Graham, Frank, *Man's Dominion* (M. Evans and Co.: New York, 1971), pp. 78-85.

[230]Ibid., pp. 128, 173.

[231]Everhart, W.D., *The National Park Service*, No. 31 (Praeger: New York, 1972); communication from Park Service to NSB staff, June 1977.

[232]See Park Service section in Part I.

[233]*Federal Funds*, Vol. II, p. 32.

basic research in the social sciences (only $27,000 supported work in the life sciences and $1,000 in the physical sciences).[234] In 1977 the estimated budget is much lower—the total being only $619,000. Basic research obligations in the life sciences are estimated at $451,000; the environmental sciences (not listed as such before) account for $49,000; and the budget for social sciences is down to $119,000. The work is split between intramural performers ($227,000) and extramural performers, primarily universities ($392,000).[235]

Summary

From its inception, the Department of the Interior "became a repository of responsibilities which seemed to fit nowhere else. . . ."[236] Its research program is a reflection of the individual goals and histories of its component parts. Although the Department contains an Office of Research and Development, that office's responsibilities are to coördinate only energy and mineral research and development.[237] The Geological Survey and OWRT are almost purely research agencies, and the Fish and Wildlife Service is heavily committed to research. All three of these agencies include a solid component of appropriate basic research in their research programs. On the other hand, it appears that the Bureau of Indian Affairs has never done any research, and the Bureau of Mines and the National Park Service currently do relatively little basic research.

Department of Health, Education and Welfare

The Department of Health, Education and Welfare (HEW) has the largest basic research program of any Government agency. By far the largest portion of this research is done by the Public Health Service (PHS).

PHS—Origins

The Public Health Service (PHS) now includes the Office of the Assistant Secretary for Health; the Alcohol, Drug Abuse, and Mental Health Administration (ADAMHA); the Center for Disease Control in Atlanta, Ga.; the Food and Drug Administration (FDA); the Health Resources Administration; and the National Institutes of Health (NIH). The Assistant Secretary for Health is *ex officio* the Surgeon General of the United States. The PHS is the Federal agency charged by law to promote and insure the highest level of health attainable for every individual and family in this country, but it originated at a time when the Federal Government did not assume any responsibility for public health or health care.

In 1798, in answer to complaints from port cities, a law was passed to tax merchant seamen's salaries to pay for their hospitalization. Hospitals were built and were administered by the Treasury Department. These hospitals were in no way research institutions, but eventually they became the instruments of the PHS. In 1870, these hospitals were in such bad condition that Army assistance was requested; Surgeon John Shaw Billings, who had created the Surgeon General's Library, the Index Medicus, and the Index Catalogue, assisted Dr. W. D. Stewart, Inspector of Marine Hospitals, in planning reform. Following their recommendations, Congress created the post of Supervising Surgeon of the Marine Hospital Service. Dr. John Woodworth, who was appointed to this position, recruited a commissioned corps of professionally qualified medical doctors which received specific legal recognition in 1889.[238]

On March 3, 1879, Congress voted to create a National Board of Health. In the confusion of rushing the bill through, provisions for a national public health organization were omitted. The Board sponsored research on a wide variety of subjects, including organic matter in the air, disinfectants, sewers, soils, diseases of food animals, adulteration of food and drugs, and sanitation. This work was done under grants to individual investigators, usually at universities. However, the Board soon collapsed because it was required to enforce a yellow fever quarantine, which it opposed. Although a quarantine had been demanded politically, once imposed it was equally unpopular politically, and the Board did not have strong allies to protect it. The quarantine became the responsibility of the Marine Hospital Service, and all medical research reverted to the Army.[239]

The Marine Hospital Service began its own research about 1887 when Dr. J. J. Kinyoun set up a bacteriological laboratory at the Marine Hospital on Staten Island. In 1888 the Service was threatened with transfer to Interior. The Service successfully defended itself by quoting Kinyoun's

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[234] *Federal Funds*, Vol. XIII, NSF 65-13, pp. 146, 150.

[235] *Federal Funds*, Vol. XXVI, NSF 77-317, Tables C-30 and C-34.

[236] *America 200*, op. cit., p. 46.

[237] *United States Government Manual 1976/77*, op. cit., p. 298.

[238] Dupree, Chapter XIII; Schmeckebier, L. F., *The Public Health Service: Its History, Activities, and Organization*, Service Monograph No. 10 (Institute for Government Research: Baltimore, 1923), pp. 2-10. Hereinafter referred to as Schmeckebier.

[239] Dupree, pp. 259-262.

report of his discovery of cholera in New York, by the statement that the Service had two scientific investigators, Kinyoun and Guiteras, and by presenting Sternberg's testimony that, although he was in the Army, it was the Marine Hospital Service which had arranged for him to be sent to Cuba to study yellow fever.[240] In 1891 Kinyoun's work was officially authorized by Congress; his laboratory was moved from its one room at the hospital to the top floor of the Butler Building in Washington, D.C., and given the title of National Hygienic Laboratory.[241] In 1901, Surgeon General Walter Wyman established a Division of Scientific Research, which included both the National Hygienic Laboratory and a newly formed Yellow Fever Institute. In the same year money was appropriated for a new laboratory building "for the investigation of infectious and contagious diseases, and matters pertaining to public health."[242] The Biologics Control Act of 1902 required the Laboratory to develop tests to control the purity and quality of biologic products such as viruses, serums, toxins, and antitoxins. The Service then became known as the Public Health and Marine Hospital Service, and a Scientific Advisory Board was mandated. The Laboratory added divisions of chemistry, pathology, zoology, and pharmacology to the original bacteriology division.

In the 10-year period 1901-1911, Wyman devoted his attention to improving medical research in the United States, for he recognized that we were far behind Europe in this respect.[243] Consequently, this period was very productive for the Public Health and Marine Hospital Service. In 1901 the Service attempted to curtail the threat of bubonic plague by investigating means to control rats (the rat-flea vector was already known). In 1902 it began to work on rocky mountain spotted fever, although a successful human vaccine was not produced until 1924. By 1910, Service investigators identified the organism responsible for tularemia, but attempts to control it were still being reported as late as 1926. Also in 1910, the problems of animal brucellosis and its human counterpart, undulant fever, were solved by Dr. Alice Evans; the solution was to pasteurize milk. In the same year, the recognition of anaphylaxis as other than a random event, with the identification of horse serum as one agent frequently responsible, appears to have been entirely a Service contribution, and its malaria program led the way in the discovery of Paris-green, diluted with inert matter, as a larvacide to control the Anopheles mosquito.[244]

PHS—Creation - 1912

In 1912 the agency's name was changed to the Public Health Service. In 1914 Dr. Joseph Goldberger proved that pellagra was not an infectious disease as previously supposed, but a result of dietary deficiency.[245] During World War I an Executive order placed the PHS in the armed services, not by direct transfer but by authorizing the Secretaries of War and Navy to use Service facilities and personnel as necessary. During the war, the PHS was effective in the detection and prevention of disease. In 1917, the Service standardized antityphoid vaccine, manufactured it in large quantities, and sent personnel into the field to administer it. The Service was also able to distribute a vaccine against typhus, a serious wartime disease, after 15 years of research and development. In one instance it developed a test for anaerobic contamination after finding tetanus contamination of smallpox vaccine; in another it identified imported bristles in shaving brushes as the source of anthrax spores when that disease appeared mysteriously. The PHS also carried out a major program in venereal disease control, but immediately after the war funds were cut off and this work was stopped.[246]

When the war was over PHS was given unprecedented responsibilities for the veterans, but these lasted for only about 2 years until the Veterans Administration was established. Activities of the 1920's included the establishment in 1922 of the Rocky Mountain Laboratory, which played an important part in conducting spotted fever research, and extensive efforts throughout the decade in ratproofing and fumigating, especially ships.

In 1930, the Hygienic Laboratory became the **National Institute of Health** and moved to the Bethesda area which it now occupies. Its new charter allowed it to accept gifts and to establish fellowships. The first fellowship was funded by a $150,000 gift from Francis P. Garvin of the Chemical Foundation.[247] The word "Institute" was eventually pluralized after other institutes were added—the National Cancer Institute (NCI) was added in 1930, the National Institute of Mental Health (NIMH) in 1946, the National Dental Insti-

[240]Furman, B., *A Profile of the United States Public Health Service*, DHEW Pub. No. (NIH) 73-269, pp. 194-196. Hereinafter referred to as Furman.

[241]Williams, C. W., *The United States Public Health Service* (Whittet & Shepperson: Richmond, 1951), pp. 177-178. Hereinafter referred to as Williams.

[242]31 Stat. L. 1137, March 3, 1901, quoted in Schmeckebier, p. 24.

[243]Furman, Chapter 11.

[244]Williams, pp. 187-189, 190-192, 245-246, 305-306.

[245]Dupree, p. 270.

[246]Williams, pp. 209, 592 et seq.; Schmeckebier, pp. 47-52.

[247]Williams, p. 169.

tute in 1948, and the National Institute on Arthritis, Rheumatism and Metabolic Diseases and Blindness in 1950. Provision was made for additional institutes to be added "as the Surgeon General shall find necessary."[248] In 1939, PHS was removed from Treasury and merged with the Office of Education and the Social Security Board to form the Federal Security Agency.

PHS—World War II and Current Trends

During World War II, PHS functioned more under its own direction than in World War I, except that it provided the medical services for the Coast Guard, which in wartime operated as part of the Navy. Wartime research emphasized work on malaria, including entomological studies to differentiate Anopheles mosquitos from other species in order to speed up eradication techniques.[249] In 1952, PHS obligations for basic research were $14.6 million, all in the life sciences and all under NIH.[250] By 1963, this amount had increased to $230.8 million for PHS, of which $217.9 million was for NIH. Reported separately from PHS, there was $1.0 million for the FDA and $44,000 for St. Elizabeth's Hospital in Washington, D.C.[251] The estimates for 1977 are $60.1 million allocated for ADAMHA, which was part of NIH in 1963 and now includes St. Elizabeth's, $670.2 million for NIH, $310,000 for the Health Services Administration, and nothing for the FDA.[252]

Breaking down the latest ADAMHA figures for 1977, this agency estimates $33.9 million for support of research in the life sciences, $18.5 million in psychology, $6.9 million in the social sciences, and smaller amounts in the other sciences.[253] Of the total, about 32 percent is intramural, 52 percent is for research performed by universities, 9 percent by other nonprofit institutions, 4 percent by State and local governments, and 3 percent by foreign countries.[254] Basic research projects are almost always initiated by the investigator. They are usually supported by grants when the investigator is in a university or other nonprofit organization and by contracts when proposals are submitted from profitmaking organizations.

NIH breaks down its 1977 estimates of basic research support into $607.6 million in the life sciences, $10.5 million in psychology, $38.3 million in the physical sciences, $3.2 million in mathematics, $6.1 million in engineering, less than half a million in the social sciences, and $3.9 million in other sciences.[255] Of the total, 19 percent is done intramurally, 0.3 percent in the FFRDC's of other agencies, none in NCI's own FFRDC—the Frederick Cancer Research Center, operated for NCI by Litton Bionetics—68 percent in universities, 10 percent in other nonprofit institutions, 1.3 percent by State and local governments, and 0.4 percent in foreign countries.[256]

NIH administers all its extramural basic research through grants. Its intramural research is done for the most part at NIH in Bethesda, Md., but the National Institute for Environmental Health Services has its facilities in Research Triangle Park, N.C. In addition, NIH has seven inhouse field activities which do basic research as well as an animal center.

The procedures used by NIH and ADAMHA for distributing research funds are generally very similar. Peer review procedures for health research supported by the Federal Government were initiated in 1902 with the establishment of the Scientific Advisory Board to assist the Surgeon General in the administration of the Hygienic Laboratory. The Cancer Act of 1937 provided for a National Advisory Cancer Council, which played a key role in recommending the award of grants; this advisory procedure was extended to grants and fellowships in all health research areas by the Public Health Service Act of 1944.

Since 1947 there has been a dual review system at NIH for all regular research grants. Proposals go to the Division of Research Grants (DRG), which reports to the Director of NIH. DRG gives each proposal to an initial review group, consisting of 15-20 specialists in that scientific discipline who determine the scientific merit of the proposal. Those proposals which are recommended for approval are forwarded to the bureau, institute, or division (BID) having cognizance. Each BID is responsible to an Advisory Council, which must concur if the BID is to make an award. Approval by the Council however does not require the BID to make an award.

In 1976, a grants peer review study team made up of NIH personnel made an extensive investigation of this system. Their report, from which the above summary was taken, includes the observation, ". . . the Study Team feels that peer review exercises the single most powerful influence on the continued high quality of the Nation's biomedical research effort . . . ."[257] ADAMHA

[248] Ibid., pp. 171-173.

[249] Ibid., pp. 649-650.

[250] *Federal Funds*, Vol. II, p. 31.

[251] *Federal Funds*, Vol. XIII, NSF 65-13, Table C-18.

[252] *Federal Funds*, Vol. XXVI, NSF 77-317, Table C-34.

[253] Ibid.

[254] Ibid., computed from Table C-30.

[255] Ibid., Table C-34.

[256] Ibid., computed from Table C-30.

[257] Grants Peer Review Study Team, "Report to the Director, NIH, Phase I," December 1976, pp. 13, 41-43, 45.

uses similar procedures, and both agencies use regularly constituted boards of outside advisers to review their in-house research.[258]

Health Services Administration

The Health Services Administration (HSA) is concerned with the delivery of health care, and estimates a budget of $310,000 for basic research in 1977, all of it intramural, all of it clinical-medical.[259] Discussions with various representatives of the Administration indicate a possibility of confusion, however. Clinical-medical is one of the subdivisions of the life sciences, but it appears that HSA is concerned not with diseases or the orders and disorders of the human body, but with how to deal with patients, especially American Indians and children, in the process of administering health care to them. Therefore, the HSA research may well be classified more properly as social science.

The National Institute of Education

The history of the education division of HEW begins in 1867 with the creation of a noncabinet Department of Education, which became a bureau in the Department of the Interior in 1869. In 1874, the title was changed to Office of Education. The Office became part of the Federal Security Agency when that agency was established in 1939.[260] No evidence was found that any research was conducted in the Office until 1952, when it reported a budget of $859,000 for basic research and $162,000 for applied research, all in the social sciences.[261] In 1953 the Office of Education became part of HEW. By 1963 the basic research budget of the Office was $4.1 million—$3.3 million of it was obligated for research in psychology and $837,000 for the social sciences. Of the total, $405,000 was spent for intramural research activities, $3.4 million for research done by other nonprofit organizations, $204,000 for work by States and cities, and $15,000 for research in foreign countries.[262] The National Institute of Education (NIE) was created in 1972 and has taken over basic research started by the Office of Education. (The organization and the manner of handling extramural research are described in the NIE section of Part I.) The funds allocated for basic research in NIE's 1977 program were reported to be $11.9 million, but more recent information indicates that this amount was cut to about $7.9 million, all in the social sciences. About 18 percent of these funds (reported as intramural) is actually the administrative cost of running the program.

Almost all the basic research supported by NIE is performed in 17 R&D centers and educational laboratories. These are run by State and private universities or by other nonprofit institutions.[263] The National Council on Educational Research (NCER), which guides NIE, has recently reviewed this basic research program in light of a National Academy of Sciences/National Academy of Education study which they had requested. They have concluded that fundamental research relevant to education should be increased, and have decided that an increased portion of NIE's research budget should be devoted to fundamental research beginning in 1979.[264]

Social Security Administration

The Social Security Administration does some research, but according to the latest submission it is not presently basic research.[265] The Office of the Secretary does do considerable research, the basic part of which is estimated at $1.6 million for 1977, all in the social sciences. This supports an Institute for Research on Poverty at the University of Wisconsin; the research conducted by the Institute is in economics and sociology.[266]

Summary

HEW conducts a large program of mission-oriented basic research. It seems clear that Surgeon General Wyman's goal of a first-class medical research organization has been achieved. PHS was prepared to be of great service during World War I. In World War II, disease detection and control had greatly improved; preventatives were available for typhus, typhoid, smallpox, cholera, plague, yellow fever, etc., and malaria was curtailed. Just as PHS played a major role in the control of infectious diseases, now it has taken the lead in the next generation of problems—heart disease, cancer, aging, mental disorders, drug abuse, and alcohol-

[258]Communications from ADAMHA and NIH to NSB staff, May, August, and December 1977.

[259]*Federal Funds*, Vol. XXVI, NSF 77-317, Tables C-30, C-34, and C-40.

[260]Miles, R. E., Jr., *The Department of Health, Education and Welfare* (Praeger: New York, 1974), p. 140.

[261]*Federal Funds*, Vol. II, p. 31.

[262]*Federal Funds*, Vol. XIII, NSF 65-13, pp. 146-150.

[263]Informal communication from NIE staff to NSB staff, September 1977.

[264]NCER Policy Resolution on Fundamental Research Relevant to Education, NCER-GP-77-02, September 16, 1977.

[265]*Federal Funds*, Vol. XXVI, NSF 77-317, Tables C-30 and C-34 (Social Security Administration no longer appears).

[266]Communication, HEW Office of the Assistant Secretary (Planning and Evaluation) to NSB staff, August 1977.

ism. Dr. Lewis Thomas, President of the Memorial Sloan-Kettering Cancer Center in New York, recently discussed the important role basic research has played in past progress and the need for it in combating the new problems:

> We tend to forget about the basic science that came indispensibly, before the elimination of such a large segment of infectious disease just a few decades back. . . . By the late 1940s the field of infectious disease was well established as an applied science. Some of the major infections which plagued us all before then have literally vanished since, and most of the others have come under effective control. . . . By the 1950s when the major programs of the NIH were being organized, there were no comparable insights into the inner mechanisms of these other great diseases of human beings. In contrast to the infectious diseases, the research on these other problems had to be started at that time virtually from scratch, with nothing at all to compare with the storehouse of banked knowledge available for infectious diseases.[267]

Two major agencies of HEW report no activities in basic research: the Food and Drug Administration and the Center for Disease Control, including the National Institute for Occupational Safety and Health.

National Aeronautics and Space Administration

The roots of the National Aeronautics and Space Administration (NASA) go back to Langley's work in aeronautics at the Smithsonian Institution. It would be difficult to improve on Dupree's account of this beginning:

> Because of the proposals of individuals in the government who had become interested in aviation and who realized that the lack of fundamental information was hampering development, President Taft appointed in 1912 a commission to study the need for a research laboratory.[64] Walcott was a member, and the report recommended a laboratory within the Smithsonian supported by appropriations. When Congress did not act, the Smithsonian on its own initiative resolved to revive Langley's laboratory to study 'the problems of aerodromics, particularly those of aero-dynamics, with such research and experimentation as may be necessary to increase the safety and effectiveness of aerial locomotion for the purposes of commerce, national defense, and the welfare of man.' The secretary was to secure the 'cooperation of governmental and other agencies in the development of aerodromical research under the direction of the Smithsonian Institution.'[65] As 'a private organization having governmental functions and prerogatives,' the Smithsonian hoped to coordinate the research of the Bureau of Standards, the Weather Bureau, and the War and Navy Departments as well as conduct the Langley Aerodynamical Laboratory, which it envisaged as a building on the Institution's grounds with a flying field in nearby Potomac Park. An advisory committee. . . was organized, consisting of the director of the laboratory, members designated by the secretaries of the Navy, War, Agriculture, and Commerce, and others appointed by the secretary of the Smithsonian who 'may be acquainted with the needs of aeronautics.[266 268]

The Comptroller ruled that the arrangement was illegal without the approval of Congress; approval was then sought by Secretary Walcott and Regent Alexander Graham Bell. The United States, where the first successful airplane was developed, was "the only first-class nation (without) an advisory committee for aeronautics and suitable research laboratories placed under its direction."[269] At the outbreak of World War I, the United States had 23 airplanes, while France had (about) 1,400, Germany 1,000, Russia 800, and Great Britain 400. Acting Secretary of the Navy Franklin D. Roosevelt approved of establishing an advisory committee, and Walcott succeeded in getting provisions for it included in the naval appropriation bill.

National Advisory Committee for Aeronautics

This action was too late for World War I; consequently no aircraft of U.S. design reached combat status.[270] However the National Advisory Committee for Aeronautics (NACA) was firmly established. It was composed of seven Government members and five public members who served without pay; its purpose was stated as follows:

> To supervise and direct the scientific study of the problems of flight, with a view to their

[267]Dr. Lewis Thomas, speaking at a 1977 symposium celebrating the 30th birthday of the Office of Naval Research.

[268]Dupree, pp. 285-286; his references are 64: unpublished study on NACA by Nathan Reingold, prepared for NSF; 65 and 66: *Smithsonian Annual Report, 1913*, pp. 7, 8, 117-119.

[269]Dupree, p. 286, quoting from Board of Regents of the Smithsonian Institution, "Memorial on the Need of a National Advisory Committee for Aeronautics in the United States," February 1, 1915, 63rd Cong., 3rd Sess., H.R. Doc. 1549, p. 2.

[270]Hirsch, R. and J. J. Trento, *The National Aeronautics and Space Administration* (Praeger: New York, 1973), p. 4. Hereinafter referred to as Hirsch.

practical solution, and to determine the problems which should be experimentally attacked, and to discuss their solution and their application to practical questions. In the event of a laboratory or laboratories, either in whole or in part, being placed under the direction of the committee, the committee may direct and conduct research and experiment in aeronautics in such laboratory or laboratories.[271]

The Army purchased land near Hampton, Va., for a joint Army/Navy/NACA laboratory, but due to the onset of war, the Army decided not to move its activities from Dayton, Ohio, and the Navy built a facility at Norfolk, Va. NACA then established its laboratories at Langley Field, which it shared with the Army, but the first wind tunnel at Langley was not ready until 1920.[272] NACA imported its theoretical base for the scientific study of aeronautics from Europe and focused particularly on aerodynamics. NASA historians give most of the credit for this hard focus to Joseph Ames of Johns Hopkins University and to Jerome Hunsaker of the U.S. Navy (later of MIT). The NACA installation at Langley Field was productive, and in 1929 British professionals described the staff there as "the only people so far who have been able to get at something like accurate results from wind tunnel experiments." The British also explained the reasons for NACA's success: "The present-day American position in all branches of aeronautical knowledge can, without doubt, be attributed mainly to this farseeing policy and expenditure on up-to-date laboratory equipment."[273] The best known product of NACA during this period was the NACA cowl (1928), which streamlined radial engines. Of greater long-range importance, however, was its careful measurement of drag penalties, which forced aeronautical engineers to find ways in which to avoid as many as possible.

NACA prospered during the depression because of low construction costs, pump-priming money from the Public Works Administration, and access to talented personnel who found Government salaries attractive. Its great achievement of this period was the codifying and systematic development of airfoil sections. Consequently, NACA wing shapes were adopted all over the world.

World War II

Additional facilities became available when World War II appeared imminent. In 1939, the Ames Aeronautical Laboratory, adjacent to the Navy's Moffet Field in California, was authorized and ground was broken. In 1940 an engine laboratory for developing improved piston engines was belatedly authorized and construction began near the Cleveland, Ohio, municipal airport. The lack of adequate engines was one of our serious deficiencies early in World War II, so it became necessary for U.S. industry to manufacture engines of British design.[274]

When Vannevar Bush led the way in the formation of the National Defense Research Committee (NDRC), he was already both chairman and admirer of NACA. He indicated that NACA should not become subordinate to the NDRC, and a memorandum of understanding was signed which gave each the necessary freedom but prevented overlap. When the Office of Scientific Research and Development (OSRD) was established the following year, its advisory council provided a coordinating mechanism.[275] NACA performed a great deal of useful work during the war, but the curing of buffeting and stalls and some materials improvements were probably the only successfully completed projects which utilized new basic research. NACA's contributions to the 115 different airplane types worked on from 1941 through 1944 were essentially the results of research done before the war and the application of the expertise acquired from having done this research. One spectacular product of NACA research was the P-51 Mustang fighter, called the best single-engine aircraft of the war; it was designed to British specifications very rapidly by North American Aircraft with much NACA assistance.[276]

Post-World War II

After World War II, the three main advances in aeronautics were the development of rocket propulsion and jet propulsion and crossing the sound barrier. Although rockets weren't taken seriously before the war, during the war they became well-known weapons; the German rocket we called the V-2 was large and formidable. The Germans also had developed a rocket-propelled interceptor late in the war. NACA became interested in rockets for research on the sound barrier. They obtained

[271]Public Law 271, 63rd Cong., 3rd Sess., March 3, 1915.

[272]Anderson, F. W., Jr., *Orders of Magnitude*, NASA History Series, NASA-Sp-4403 (GPO: Washington, D.C., 1976), pp. 2-3. Hereinafter referred to as Anderson.

[273]Ibid., p. 3; most of the material in this chapter on the work of NACA is taken from Anderson.

[274]RADM A. B. Metsger, USN (Ret.), private communication to NSB staff, June 1977.

[275]Dupree, p. 370; Stewart, pp. 15-16.

[276]Anderson, pp. 7-8; Hirsch, pp. 6-7; NASA communication to NSB staff, December 1977.

a facility on Wallops Island, Va., from the Navy and set up a Pilotless Aircraft Research Division there; this later became the Wallops Flight Center.

Consideration of jet propulsion was inhibited by a Bureau of Standards study which concluded in 1923 that "propulsion by the reaction of a simple jet cannot compete, in any respect, with air screw propulsion at such flying speeds as are now in prospect." There is nothing wrong with the statement except that Americans seemed to forget the final caveat regarding flying speeds. By 1941, both Germany and Britain had developed and flown turbojets, so Vannevar Bush appointed a Special Committee on Jet Propulsion.[277] The military supported a little industrial research on jet engines, but there was no significant United States effort until NACA began a formal program in 1943; consequently, American jet aircraft were not sufficiently developed for combat before the end of the war.

Although it was evident that jet- and rocket-propelled aircraft had the potential of crossing the sound barrier, wind tunnels choked up at air speeds approaching the speed of sound. NACA began research on a transonic wind tunnel in 1943, but the first manned aircraft intended to break the sound barrier was started in 1944 without one. Designated the X-1, this aircraft was a joint venture of NACA and the military services. Propelled by a liquid fuel rocket engine, it exceeded Mach 1 in 1947.

In 1950 the transonic wind tunnel was successfully built by using a "slotted throat." Within a year its development led to the discovery of the area rule which dictates the relative sizes of wing and fuselage to minimize transonic drag. This discovery enabled the development of the first fighters able to exceed Mach 1 in level flight. In the mid-1950's, supersonic wind tunnels became available. In the meantime, NACA's D-558-2 reached Mach 2 in 1953. Aircraft of this type "perilously filled in the flight envelope for transonic and supersonic flight and provided the design for generations of post-World War II military aircraft."[278]

In 1952, at the request of its Committee on Aerodynamics, NACA began consideration of unmanned and manned flight at altitudes from 50 miles to infinity and at speeds from Mach 10 to the velocity of escape from the earth's gravity. In 1954 the Air Force and Navy collaborated to develop an X-15 which achieved Mach 6 and an altitude of 108 kilometers. The Army did research using captured V-2 rockets but their performance was so erratic that many experiments were lost; the Navy developed the Viking rocket as a replacement research vehicle and it was quite successful.

In 1955 NSF, acting as agent for a number of proponents, proposed that the United States put a scientific satellite into orbit during the International Geophysical Year (IGY) (July 1, 1957, to December 31, 1958). The Defense Department was designated to take on the project, but with no interference with military rockets. The "no interference" provision dictated that a new booster be developed as well as the upper stages The Navy developed successful second and third stages, but the booster was extremely modest, essentially a Viking adapted to kerosene fuel instead of alcohol. A series of test firings failed, some spectacularly.

Post-Sputnik

On October 4, 1957, the USSR launched Sputnik I into orbit; there was an immediate strong reaction in the United States. The Army was authorized to fire the sub-rosa satellite assembly which the Army Ballistic Missile Agency (ABMA) had built at Huntsville, using the Army's military Redstone rocket as booster, and they successfully orbited Explorer I with a basic research experiment of Dr. James Van Allen's in it.

Although Vanguard did succeed in putting three satellites into orbit during the IGY, the Nation was disappointed.[279] Not only had the USSR technologically upstaged the United States, but many U.S. officials were alarmed at the apparent power of the Russian ICBM booster. NACA responded with a proposal to conduct research in astronautics. However, in 1958, Congress passed the National Aeronautics and Space Act, which provided for the change of NACA to NASA within 90 days and the subsequent transfer of space-related functions of other agencies at the discretion of the President over a period of 4 years.[280] Project Vanguard was transferred from the Navy, with NRL and the U.S. Naval Station at Anacostia providing space until new quarters became available at Beltsville, Md. (now the Goddard Space Flight Center). Other senior NRL scientists and engineers were also recruited by NASA. Two Air Force lunar probes and an Air Force large rocket engine project were transferred, as were two lunar probes and three satellite projects from the Army. After considerable Army resistance, the Jet Propulsion Laboratory and the Army's contract with the California Institute of Technology to run it were also

[277]Hirsch, p. 6.

[278]Anderson, p. 11.

[279]Rosholt, Robert L., *An Administrative History of NASA, 1958-63*, (NASA; Washington, D.C., 1966), pp. 5-6. Hereinafter referred to as Rosholt.

[280]Rosholt, pp. 8-15.

transferred. It was another year before the Army gave up the Saturn booster and the part of ABMA supporting it; this became the nucleus of what is now the Marshal Space Flight Center in Huntsville, Ala.[281]

Soon after the formation of NASA, Project Mercury was initiated for the purpose of achieving manned space flight. However the Soviet Union was also first in achieving this goal. Responding to this additional shock, President Kennedy proposed the Apollo Program, which was intended to send a man to the moon and back by 1970. NASA acquired the launch facility which came to be called the Kennedy Space Center and built the Manned Spacecraft Center (MSC) in Houston, Tex. It also embarked on an extensive development program backed up by relevant basic research.

That basic research played an important role in NASA's massive program is illustrated by the changes in priorities and the increased spending since 1952. NACA's basic research obligations in fiscal year 1952 were reported as $17.7 million, all for research in the physical sciences.[282] In contrast, NASA's reported obligations for basic research in 1963 were $210.3 million, of which $7.2 million was spent for research in the biological sciences, $0.9 million in psychology, $176.5 million in the physical sciences, $1.6 million in mathematics, $23.9 million in engineering, and $0.1 million in social sciences. Of the total $210.3 million, 18.7 percent was intramural; 57.9 percent was for research performed by industry directly, and 0.5 percent for research performed in centers operated by industry; 9.6 percent was for research performed in educational institutions and 11.4 percent in centers operated by educational institutions; 1.5 percent was for research performed by nonprofit organizations and 0.3 percent by centers operated by nonprofits; and 0.1 percent was for research performed in foreign countries.[283] Estimated obligations for 1977 are $319.7 million for basic research—$13.7 million in life sciences, $0.8 million in psychology, $198.1 million in the physical sciences, $66.9 million in the environmental sciences, $3.3 million in mathematics, $36.7 million in engineering, $100,000 in the social sciences, and $184,000 in other sciences. The intramural portion has risen to 49 percent; the industrial share has dropped to 26 percent; the universities' portion has increased to about 21 percent (plus 2.6 percent at FFRDC's operated by universities). Other nonprofit institutions account for less than 1 percent and FFRDC's operated by nonprofits account for another quarter of that amount. A negligible amount was performed by State and local governments and by foreign countries.[284]

These figures reflect the changes that have occurred. During the 1960's, the primary emphasis of NASA was on the manned space-flight program. Even this program made use of opportunities for basic research; of the 52 experiments done for the Gemini project, for example, 17 were scientific and 8 were medical.[285] The Surveyor project included a number of very interesting basic research experiments. The Apollo project provided further opportunity for numerous scientific experiments both on the moon and in space.

Concurrently with the manned space-flight program, scientific unmanned satellites were also being launched. The in-house component of this satellite-based research, although small at first, has grown large. The usual procedure has been to invite proposals for experiments to accompany a satellite planned for a specific mission, for example, a solar observatory. The decision on which experiments would be accepted for the mission is usually made after considering the recommendations of an advisory committee. Weight, dimensions, and power would be allocated to each accepted experiment. An advisory committee would also recommend general features such as pointing accuracy and mission lifetime. The experimenters would deliver their instruments by a set date to the payload integrator, an engineering group at a NASA activity or at one of its contractors. This group would test each package to insure its ability to survive launch stresses and to perform in the space environment. It then would integrate the experimental packages with the NASA-provided services such as the payload structure and the power source. The whole payload then would be tested and sent to another contractor to be mated with the launch vehicle. After the launch, the data collected usually would be transmitted to Goddard for processing by Goddard personnel or by the experimenter or by a combination of the two. Since project management usually resides with one of the engineering-oriented field groups, some demand has arisen for more influence by outside scientific experimenters on mission priorities. For example, there is current demand for a Space Telescope Science Institute to be run by some organi-

[281] Ibid., pp. 44-47, 71, 90.

[282] *Federal Funds*, Vol. II, p. 33.

[283] *Federal Funds*, Vol. XIII, NSF 65-13, Tables C-18 and C-22, as revised. NASA obligations for basic and applied research originally reported for 1963 and for 1966-74 inclusive have been revised downward in accordance with OMB guidelines. Other years in the 1960's should be similarly revised but this has never been done.

[284] *Federal Funds*, Vol. XXVI, NSF 77-317, Tables C-30 and C-34.

[285] Anderson, p. 54.

zation outside of NASA which would represent the users of the instrument. Similarly, the x-ray astronomers have requested an institute to deal with NASA on the tradeoffs which would affect the scientific capabilities of future x-ray observatories which may be flown in the Space Shuttle.[286]

NASA's basic research in the life sciences has been largely concerned with exobiology and the effects of weightlessness on all living organisms. In fact, the concepts of life detection systems were first developed in the exobiology program. This work reached its consummation in the recent Viking experiment to determine whether life exists on Mars. An even more important task was the development of planetary quarantine procedures to safeguard other planets from us and, moreover, to protect us from the possibility of dangerous microorganisms being introduced into our environment by visitors or equipment returning from the moon or from other planets. Another program developed satellites to receive telemetry from tagged wild animal subjects and to sense the environment. There were also laboratory and geological studies on the origin of life, work which included Joshua Lederberg's research on the sequence of amino acids and Cyril Ponnamperuma's on their natural synthesis. Some work related to man's ability to survive in space involved basic studies in mammalian physiology and response to stress. The MSC, now the Lyndon B. Johnson Space Center (JSC), became an important location for some of this work. All these programs used both contracts with universities and in-house efforts.[287]

Once the Apollo program had achieved its initial goal, the willingness to pay the cost of continuing a high level of effort began to fade. Consequently the NASA budget began to contract. Skylab followed Apollo, and the next stage of manned space flight activities will be the Space Shuttle. In the meantime, a series of unmanned vehicles has been providing a great deal of basic information about the solar system and beyond. Uhuru and HEAO-A are still yielding x-ray data; orbiting solar observatories like OSO-7 have provided new information on the sun; and interplanetary probes and landers in the Pioneer, Mariner, and Viking series have greatly changed and improved our ideas about Mercury, Venus, Mars, and Jupiter. NASA also has launched successful research satellites for other agencies, e.g., EROS for USGS and the SolRad series, which observes the sun for Navy.

The reduction in NASA's R&D budget from \$5.0 billion in 1965 to \$3.0 billion in 1974, followed by a slight rise in 1977 to \$3.5 billion, did not affect the basic research component appreciably. Caution must be exercised in extracting and interpreting published figures on NASA basic research because some have since been revised downward by a factor of over two. The actual trend however has been essentially flat for the last 10 years.[288]

In summary, NACA was an advisory agency for the first 10 years. It then became a research agency, doing very little design and development and virtually no operations. In contrast, NASA has had development and operation responsibilities in addition to its research function. NACA was directed by a committee while NASA has been administered hierarchically.[289] NACA was created for scientific reasons, and it accomplished its job relatively unaffected by politics. NASA, on the other hand, was created for political reasons. This fact and NASA's high visibility have meant that political considerations sometimes required compromise with purely scientific judgments. However, NASA has made a major contribution through basic research performed both in-house and under contract. In addition, NASA has become a service organization providing satellites and other space vehicles on which experimenters supported by other agencies may conduct important basic research.

Department of Energy and Energy Research and Development Administration

The timing of this report precludes any direct consideration of the Department of Energy (DOE) and the changes which its establishment are bringing about. ERDA, which has been absorbed by the newly formed DOE after less than 3 years of existence, was established in 1974. It brought together most of the nonregulatory functions of the AEC, the energy research activities of Interior, chiefly the Office of Coal Research (OCR) of the

[286]"Institutional Arrangements for the Space Telescope" (NAS: Washington, D.C., 1976); draft of a proposal for an Institute for X-ray Astronomy, June 5, 1975, prepared by H. Friedman and R. Giacconi; "An International Discussion of Space Observatories," a joint publication of the National Academy of Sciences and the European Science Foundation (1976), pp. 10-11.

[287]Informal communication from Dr. Orr Reynolds, Director, NASA Biosciences Program 1962-1970, to NSB staff, August 1977.

[288]*Federal Funds*, amended by communication from NSF (SRS) to NSB staff, August 1977. (See footnote 283.)

[289]Communication from NASA to NSB staff, December 1977.

Bureau of Mines, solar and geothermal research responsibilities of NSF, and some alternative automotive-power work of the Environmental Protection Agency (EPA).[290]

Origins

The oldest Government research program that ERDA administered was fossil fuel research, which dates back to the Navy's pre-Civil War sponsorship of measurements of the heat of combustion of coal.[291] Similar measurements initiated coal research in what later became the Bureau of Mines. A fuel testing laboratory was established in Pittsburgh and a technologic branch was made part of the Coast and Geodetic Survey in 1907. The budget of this branch reached $500,000 in 1909 and the following year the branch became the nucleus of the new Bureau of Mines. Testing of fuel was a $100,000 program at the Bureau in 1911, growing slowly to $135,000 by 1918. Petroleum and natural gas research began in 1915. Ten mining experiment stations were funded that same year, the number increasing to 13 by 1921.[292]

ERC's

In 1974, when ERDA was established, the Bureau of Mines had five laboratory complexes which conducted research and engineering related to fossil fuels. These laboratories were transferred to ERDA, where they became known as Energy Research Centers (ERC's). ERDA states in its section of Part I that it has not reported any of the work of the ERC's as basic research in its annual report to NSF, but that much of it would be included in its internal "basic/fundamental research" category. It is likely that at least some of the work was reported as basic research when those laboratories were under the Bureau of Mines.[293]

In its early days the Pittsburgh ERC did important research on explosives and began programs of basic research on the nature of coal and on the fundamentals of combustion. Since coal is a mixture of minerals, each of which is extremely complex chemically, understanding its composition is especially important before trying to alter it. The basic research included employment of many analytical techniques, including hydrogenation, to make coal soluble and thus to make possible the determination of an average molecular weight. The justification for doing this basic research is demonstrated by its application to coal carbonization, liquefaction, and gasification. Results of many years of important research in combustion by Bernard Lewis and Guenther Von Elbe at Pittsburgh are contained in their classic reference book *Combustion Flames and Explosions of Gases*, published in 1961. Combustion research provided the complete characterization of the various oxides of nitrogen; this information is important for air pollution research. Another basic research program of great importance at Pittsburgh has been studies in catalysis.

Another ERC with a long history of basic research is in Bartlesville, Okla. One research group has specialized in the preparation of ultra-pure hydrocarbons and the precise determination of their thermodynamic properties. The Bartlesville laboratory developed the rotating bomb calorimeter, now widely used, and techniques for using large pore materials for gas chromatography. Another program of the laboratory was the characterization of crude oils and brines. The Bartlesville data and those of other researchers were put in computer form as an international data bank. A major basic research effort in recent years has been the study of surfactants and the development of techniques for their evaluation. Surfactants are chemical compounds used in the secondary and tertiary recovery of oil.

The Laramie ERC in Wyoming is a former branch of the Bartlesville laboratory. In a program jointly sponsored by the American Petroleum Institute and the Bureau of Mines, the Laramie laboratory synthesized a series of nitrogen and sulfur compounds to be used as standards. Laramie has also done extensive research on the characterization of asphalt. Its most significant work has been on oil shale. It has studied its geologic history, occurrence, physical and chemical characteristics, and behavior under chemical or thermal attack, and observed the nature of its decomposition products. These studies led to interesting discoveries, such as identifying large quantities of the relatively uncommon minerals nahcolite and nordstrandite in the very large Green River formation. Nahcolite is natural sodium bicarbonate which can be used to burn high-sulfur western coal relatively cleanly. The nordstrandite and the much more plentiful dawsonite in this formation provide a potential source of aluminum.[294]

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[290] *United States Government Manual 1976/77*, op. cit., pp. 476-478.

[291] Dupree, pp. 50-51.

[292] Powell, F. W., op. cit., pp. 2-6.

[293] ERDA assistance was requested so that the information in Powell (ibid.) could be updated. Information in the following paragraphs was provided to NSB staff directly from the ERC's.

[294] In addition to a private communication to NSB staff from Dr. Howard Jensen of the Laramie ERC, considerable information on this subject is contained in "Oil Shale Technology," Hearings, Subcommittee on Energy, Committee on Science and Astronautics, U.S. House of Representatives, 2nd Session (May 1974), especially pp. 485-504.

The Morgantown, W. Va., and Grand Forks, N. Dak., ERC's are oriented more toward engineering than the other laboratories. Grand Forks did not conduct basic research on its specialty, lignite coal, because that work had been done earlier, chiefly in Germany. However, the Morgantown laboratory found that basic research was necessary to support both its coal conversion program and its enhanced petroleum and gas production programs.

The present Morgantown laboratory dates back to 1954, but a smaller laboratory had been founded in 1946. Some examples of basic research conducted at Morgantown are studies of alkali metal contamination of producer gas, studies of eastern gas shales (similar to the oil shale research of the Laramie ERC), and studies of magnetism to gain a better understanding of the operation of magnetic separation systems.

AEC

Much of the basic research of ERDA was based on that of the AEC, and the current high-energy and nuclear physics programs, for example, continue the line of scientific inquiry which led to the current applications of nuclear energy. The first Federal Government money for such research was some $2,000-3,000 obtained by Ross Gunn of the Naval Research Laboratory immediately after the revelation by Nils Bohr (alias Nicholas Baker) on January 26, 1939, that Otto Hahn and Friedrich Strassman had demonstrated the fission of uranium in their laboratory in Germany. Gunn's proposal was to do the research which would enable the Navy to build a nuclear submarine. In addition to experimental confirmation of fission, reported by four laboratories in the February 15, 1939, issue of the *Physical Review,* research on fission and related physics and chemistry became very active in many laboratories. Of particular importance was the research of two groups at Columbia University, Walter Zinn and Leo Szilard in one, and Enrico Fermi, H. B. Hanstein, and Herbert Anderson in the other. These physicists discovered that more than one neutron was emitted per fissioned atom and, of key importance, that some of these neutrons were delayed, making control of a chain reaction possible. Allardice and Trapnell state that the Germans did not discover the delayed neutrons and this was the cause of the failure of their wartime nuclear program.[295]

Szilard sought support for his research from NRL but received only "sympathetic understanding," while Fermi tried both the Army and the Navy with no success. Szilard recruited Eugene Wigner of Princeton and, together with Albert Einstein, they composed a letter to President Roosevelt. In response, the President appointed an Advisory Committee on Uranium with Lyman Briggs, Director of NBS, as its chairman. Some funds for research were provided by the Army and the Navy. OSRD saw to it that funds were made available for the measurement of fundamental constants. A special committee was appointed by NAS, and, in May 1941, the committee recommended a strongly intensified effort.[296] The history of wartime atomic energy research was recorded in the "Smyth Report."[297]

The Smyth Report is credited with being the key to civilian participation in postwar nuclear energy matters.[298] When the May-Johnson Bill proposed to continue military control, there was revolt of concerned scientists, especially from Chicago and Oak Ridge. To communicate their ideas they founded the *Bulletin of the Atomic Scientists.* Senator Arthur Vandenburg responded to their pressure by introducing a resolution to establish a joint Senate-House committee to study the problem. The resolution passed, and Senator Brian McMahon became chairman of the joint committee. The McMahon Act of August 1, 1946, established the AEC as a civilian agency to control the nuclear energy program.

Basic research was a key element in the successful wartime program under the Manhattan District of the Army, and it remained important to the AEC throughout the Commission's life. The AEC supported major research programs in nuclear physics, transuranic element discovery, isotope discovery, radiochemistry, radiobiology, materials research, and mathematics. Later, basic research was conducted in plasma physics and high-energy physics. "There (was) clearly no limit to AEC's search for new knowledge, as long as it (bore) some relationship to atomic energy."[299]

Obligations reported to NSF for 1952 show that the AEC then had the largest basic research program of any Federal agency, 28 percent of the U.S. total. It reported $3.8 million in the life sciences, $30.3 million in the physical sciences, and zero in the social sciences.[300] By 1963, AEC's ba-

[295]Allardice, C. and E. R. Trapnell, *The Atomic Energy Commission* (Praeger; New York, 1974), p. 5. Hereinafter referred to as Allardice.

[296]Ibid; Baxter, J. P., III, *Scientists Against Time* (Little, Brown: Boston, 1950), pp. 419-447.

[297]Smyth, H. D., "A General Account of the Development of Atomic Energy for Military Purposes" (U. S. Army: Washington, D.C., 1945). Reprinted by Princeton University Press, 1948.

[298]Allardice, pp. 8-9.

[299]Allardice, p. 84.

[300]*Federal Funds,* Vol. II, Tables B-5 and B-7.

sic research obligations were $218.6 million, with $48.7 million in the life sciences and $169.3 million in the physical sciences. These obligations can be further subdivided—the life sciences into $30.7 million for the biological sciences, $17.0 million for the medical sciences, and $1.5 million for the agricultural sciences; and the physical sciences into $149.7 million for the physical sciences proper, $4.9 million for the mathematical sciences, and $14.7 million for the engineering sciences.[301] Of the $218.6 million total, $146.7 million was classified as extramural but the research was performed chiefly at national laboratories operated for the AEC by a variety of contractors. Of the rest, $51.8 million was for research performed by educational institutions and $6.5 million for that by industry. AEC reported $4.5 million as intramural.[302]

Current Trends

During 1975, the fiscal year during which it was established, ERDA's reported estimate of obligations for basic research in the life sciences was $15.6 million for 1975 and $17.6 million for 1976. One year later, in 1976, the figures reported were zero for both 1975 and 1976 and also for 1977. However in 1977, the pendulum swung back and the figures reported for 1976 and 1977 were both over $24 million for basic research in the life sciences. There is no indication that actual changes in program accounted for these fluctuations.[303]

Some research was transferred from NSF in the solar energy and geothermal fields, but the dollar value of these projects was small. With the research of the ERC's not included in the basic research reported by ERDA, the 1977 ERDA basic research obligations probably reflect the trends in the research programs which came from the AEC. Estimated obligations for 1977 are $390.7 million total for basic research, divided into $24.9 million in the life sciences, $297.5 million in the physical sciences, $3.5 million in the environmental sciences, $6.8 million in mathematics, and $58.0 million in engineering. Of the total, $311.1 million is for research performed by ERDA's FFRDC's and $77.0 million for that by universities and colleges. That basic research which is performed by other nonprofit institutions, industry, and in-house personnel amounts to $2.6 million.[304]

[301] *Federal Funds*, Vol. XIII, NSF 65-13, Table C-22 as subsequently revised to correct NASA reported obligations.

[302] Ibid., Table C-18.

[303] *Federal Funds*, Vol. XXIV, NSF 75-323, Tables C-34 and C-35; Vol. XXV, NSF 76-315, Tables C-33 and C-34; Vol. XXVI, NSF 77-317, Tables C-33 and C-34.

[304] Ibid., Vol. XXVI, Tables C-30 and C-34.

ERDA had less than 3 years in which to integrate very diverse programs and to bring together various groups of personnel, each of which had their own operating history, in an attempt to build an agency with a new focus. The newly formed Department of Energy now faces the task of continuing what was started by ERDA and accomplishing further integration and refocusing.

Veterans Administration[305]

The Veterans Administration (VA) was established in 1930 to bring together all groups responsible for veterans' benefits. In our early history there were no veterans' benefits except pensions; these were usually granted many years after a war. For example, pensions were distributed 52 years after the Revolution and 18 years after the Spanish-American War.

Origins

Caring for disabled, sick, and homeless veterans has been a national concern since before the Civil War. The Soldiers Home was founded in Washington, D.C., in 1851 but with very little support from appropriated funds. In 1865 a National Asylum for Disabled Volunteer Soldiers and Sailors was established by act of Congress. Several such asylums were built and their names were changed to "homes" in 1873.

After World War I, the United States had 204,000 wounded to be cared for, and the PHS was expected to take care of them. The Army and the Navy wanted to hold patients until they had received maximum hospital care, but the veterans wanted to go home. At the same time, a more generous Government had provided war risk insurance under an office of that name, and a rehabilitation division under the Federal Board for Vocational Education. In 1921 a committee was appointed under the chairmanship of General Charles G. Dawes to alleviate the confusion. They met continuously from April 5, 1921, until their report to the President was ready on April 7, 1921. The committee recommended immediate consolidation of responsibility under the Office of War Risk Insurance; later in the year, that Office and the Rehabilitation Division were made the nucleus of a new Veterans Bureau. The following year 57 PHS hospitals and the PHS personnel of the 46 of these that were operational were transferred to the Veterans Bureau. After two difficult

[305] Except where otherwise indicated, this entire section was taken from Adkins, R. E., "Medical Care of Veterans," House Committee Print No. 4, 90th Congress (GPO: Washington, D.C., 1967).

years, the Bureau gradually brought order out of chaos.

Brigadier General Frank Hines, who took over the Bureau in 1923, appointed medical consultants in 1924; one group of consultants was the Investigation and Research Group. Following this first indication of involvement in research, General Hines created a research section in the Medical Service of the Bureau.

Creation - 1930

The Veterans Bureau, the Bureau of Pensions, and the national homes were merged to form the Veterans Administration in 1930, with General Hines as the first Administrator. The VA conducted research, including basic research in the field of medicine and closely related sciences. The early history of VA medical research is described well in the Administration's own words:

> Medical research was a very modest program in the VA at the end of World War II. Such medical research as existed at that time was almost entirely conducted by contracts with members of medical schools which were affiliated with the VA. When the Congress made its first appropriation of VA funds earmarked for medical research in fiscal year 1955, the total research funding was a mere $4.8 million.
>
> Greater promise seemed to lie in intramural research programs which were augmenting the medical research contract program, and in 1956 the contract program was entirely supplanted by intramural research projects. That first year in which the VA directed its medical research, individual research investigators reported on 3,644 research projects, and made enough progress to have 900 reports published in professional and scientific journals.
>
> The early VA medical investigators were quick to discover and to put to the test one of their most valuable assets—the cooperative study. In a cooperative study, investigators from any number of different VA facilities may agree to study a selected problem under uniform guidelines. The unique quality of VA cooperative studies is that the investigators may rapidly amass significant statistics by drawing upon the largest patient population available to any single agency in the Western World.
>
> One of the earliest of these cooperative studies was initiated in 1946 in cooperation with the Armed Forces, to study the effectiveness of the chemotherapy for tuberculosis. The success of this study in determining the optimum medical treatment caused the management of that disease to become so effective that the VA was able to close or convert all of its tuberculosis hospitals to general medical and surgical care. The cooperative study scored another major success in finding the most effective chemotherapy for treating neuropsychiatric patients which threatened to tax the VA neuropsychiatric (NP) hospitals beyond their capacity after the end of World War II. The success of this study enabled the VA to care for the NP patients in existing facilities at a time when it had been thought that the number of NP hospitals would have to be doubled at a cost estimate approaching a billion dollars.
>
> The classic VA cooperative study on the benefits of treating mild hypertensive patients with antihypertensive medicine established the value of early treatment of high blood pressure in prolonging active, useful life and comfort in the Nation's aging population. Earlier findings showed that the risk of crippling or fatal strokes is directly related to the height of a person's blood pressure, and that proper treatment now available will reduce the risk of having a stroke by 75 percent. This cooperative study is largely responsible for a national and probably world-wide mobilization of health care resources to find and treat effectively those persons who are developing even mild high blood pressure.[306]

The VA reported that all its research was applied until 1957, when it reported obligations of $1.2 million for basic research in the medical sciences.[307] The following year the Congress amended the VA charter to specifically include medical research in the functions of the Department of Medicine and Surgery. Obligations for basic research peaked in 1969 at $6.4 million, the peak perhaps somewhat connected with exotic diseases of Southeast Asia.[308] Of the $6.4 million, $5.8 million supported research in the life sciences ($3.8 million for clinical-medical, $1.6 million for biological, and $0.4 million for other life sciences), $450,000 in psychology, $90,000 in the physical sciences, $55,000 in engineering, and $25,000 in the social sciences.[309] The latest estimates for 1977 obligations for basic research are $9.3 million, sharply up from last year's estimates for the same year. All this basic research is reported as intramural; $7.8 million goes for research in the

[306] "The VA Medical Research Program: An Abbreviated History," prepared by the VA Department of Medicine and Surgery, 1977, as part of an official report.

[307] *Federal Funds*, Vols. II-IV; Vol. VII, NSF 58-30, Table 11.

[308] *Federal Funds*, Vols. XVIII-XX, NSF 69-31, 70-38, 71-35.

[309] *Federal Funds*, Vol. XIX, NSF 70-38, Tables C-33 and C-39.

life sciences, $1.2 million for work in psychology, and $325,000 in unidentified sciences.[310] This year's breakdown of basic research in the life sciences is $3.9 million for clinical-medical research, $1.9 million for other medical, $1.9 million for biological, and $93,000 for work in other life sciences.[311]

Current Trends

The year 1977 has been a highly significant one for VA medical research in that Andrew V. Schally of the VA Hospital, New Orleans, La., and Rosalyn S. Yallow of the VA Hospital, Bronx, N.Y., were two of the three scientists who shared the Nobel Prize in Physiology or Medicine.

Department of Labor

The Department of Labor originated as a Bureau of Labor in the Department of the Interior in 1884. It became an independent department without cabinet rank in 1888, a bureau again in the new Department of Commerce and Labor in 1903, and finally the ninth executive department in 1913. The Grossman history of the Department makes no mention of research.[312]

Much of what is referred to as research in Labor appears to be library research, but this Department, following the Bureau of the Census, was one of the first Government agencies to undertake significant research in the social sciences. This work was done under the Bureau of Labor Statistics (BLS), which currently reports no basic research.[313] During the 1940's, before the annual reports on research efforts were started, BLS made important contributions to input-output (I/O) analysis, a very important economic research tool.

In 1952, the first year NSF published reports on basic research, Labor reported none. In 1955, however, Labor reported basic research obligations of $720,000, which were divided among four bureaus. The largest program was that of BLS with $375,000; all research was intramural.[314] Labor's basic research programs and those of BLS both peaked in 1956-57, decreased sharply in 1958, and reached a new peak in 1971—$2.5 million for the Department, $1.4 million of that for BLS. Then in 1972 the Department's total decreased again to $1.1 million, with no basic research at all for BLS.[315] Since then the basic research level for the Department has declined to the $785,000 total estimated for 1977. Of this amount, $670,000 is for research performed at universities and colleges for the Employment and Training Administration and $115,000 for work conducted in-house by the Labor-Management Services Administration.[316]

The National Science Foundation

The National Science Foundation (NSF) was established in 1950 to promote the progress of science through the support of basic research and education in the sciences.[317] Several previous efforts to create a national department for science had failed. NAS, responding to a request from the Allison Commission, had recommended such a department in 1884.[318] In 1945, Vannevar Bush recommended the establishment of a new agency

> adapted to supplementing the support of basic research in the colleges, universities, and research institutes, both in medicine and the natural sciences, adapted to supporting research on new weapons for both Services, (and) adapted to administering a program of science scholarships and fellowships.[319]

He explicitly excluded social sciences and the humanities, although he acknowledged their importance.[320] Senator Warren Magnuson and Representative Wilbur Mills unsuccessfully introduced bills to carry out Bush's recommendations. In 1947, the President's Scientific Research Board recommended the establishment of a National Science Foundation to make grants in support of basic research.[321] They excluded from their study the social sciences and military and atomic energy research programs.[322] That same year President Truman vetoed S.526, which would have created the Foundation, on the grounds that it had so much authority vested in a part-time board that it appeared to violate the President's constitutional authority.[323] The first Hoover Commission reiter-

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310 *Federal Funds*, Vol. XXVI, NSF 77-317, Tables C-30 and C-34.

311 Ibid., Table C-40.

312 Grossman, J., *The Department of Labor* (Praeger: New York, 1973).

313 Dupree, p. 335; *Federal Funds*, Vol. XXVI, Table C-34.

314 *Federal Funds*, Vol. V, NSF 56-19, Table 4.

315 *Federal Funds* series.

316 *Federal Funds*, Vol. XXVI, NSF 77-317, Table C-30.

317 *United States Government Manual 1976/77*, op. cit., p. 579.

318 True, op. cit., pp. 295-297; Dupree, pp. 215-217, 293, 377.

319 Bush I, p. 4.

320 Ibid., p. v (letter of transmittal to President Truman).

321 Steelman, op. cit., p. 6.

322 Ibid., pp. viii-ix.

323 Schaffter, D., *The National Science Foundation* (Praeger: New York, 1969), p. 11. Hereinafter referred to as Schaffter.

ated the Steelman recommendation in 1949, and in 1950 NSF was finally established.[324]

Several agencies developed basic research programs prior to NSF's formation, and questions arose concerning the new Foundation's relationship with these existing activities. During the debate on the NSF legislation, a proposed division of national defense was eliminated and it was left to the Secretary of Defense to initiate a request if he needed the help of NSF for national defense.[325] There were no clear provisions regarding NSF's relationship with the basic research programs of AEC and NIH, but Alan Waterman, as the first Director of NSF, was concerned with insuring the adequacy of the total national effort and developing a rounded program for the Foundation rather than preventing others from doing what research they found necessary.[326] The following historical account describes NSF's early planning and policy formation:

> Initially, at least, the NSF was given two sets of functions: to develop national science policy including contributions of other agencies, and to implement that policy, as needed. However, immediately after its establishment, the Foundation encountered effects of an economy drive and then the diversion of the Korean war that limited its ability to carry out its extensive responsibility. . . . (P)lanning and some programs were undertaken . . . in support of the three primary components of a scientific capability: research, manpower development, and communication. From a variety of options, the Foundation chose to support research through grants for individual projects rather than (through) programs (of) general institutional support. Grants have been selected on the basis of merit of research proposals by review panels comprising the Nation's leading experts in the respective field.[327]

The Act of 1950 specifically prohibited the Foundation from operating any laboratories or pilot plants.[328]

In 1954, Executive Order 10521 reiterated the Foundation's responsibility for science policy, a responsibility which had been given little emphasis until this time. As part of the reaction to Sputnik, President Eisenhower and, later, President Kennedy took a series of steps which resulted in the partial transfer of the "national policy responsibilities of NSF which had been assigned by Congress, but which it could not or would not implement,"[329] to a new Office of Science and Technology in the Executive Office of the President. The 1965 review, from which the above quotation was drawn, reported NSF's accomplishments of the first 15 years:

> In the first instance, the fact that the United States has sustained its World War II preeminence in science is now universally accepted . . . It is also generally believed that the influence of the Foundation was far out of proportion to its budget . . . . Judging from annual reports of Dr. Alan T. Waterman, its first Director, it is clear that he saw the role of the Foundation as one of setting the tone and national standards, and serving as a catalytic agent without undue interference, to assure the quality of U.S. science while other agencies assumed more the role of massive support . . . the present strength of U.S. science speaks to the overall accomplishment.[330]

This report was prepared in 1965 for seven weeks of hearings before the Subcommittee on Science, Research, and Development of the House Committee on Science and Astronautics. The hearings, recorded in House Report No. 1236 of January 1966, resulted in a bill introduced by Congressman Emilio Daddario in March 1966 to implement the recommendations of that report.[331] A similar bill with some amendments initiated by the Senate's Special Committee on Science became law in July 1968.

The 1968 Act

This act significantly broadened the Foundation's authority and increased the responsibility of the National Science Board in the area of science policy. Of particular significance to this report is the provision that the Board render an annual report to the Congress, through the President, on the status and health of American science.[332]

Another very important change designated in the 1968 Act was the specific inclusion of support for the social sciences as one of the Foundation's responsibilities. The 1950 Act had not mentioned the social sciences, but Bush's initial recommen-

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[324] Ibid., pp. 9, 11.

[325] Waterman, A. T., Introduction to 1960 reprint of *Science, the Endless Frontier,* pp. xii-xiii.

[326] Ibid., pp. vii-xii, especially xii.

[327] U. S. Library of Congress, *The National Science Foundation: A General Review of Its First 15 Years* (GPO: Washington, D.C., 1965), p. 3. Hereinafter referred to as *First 15 Years.*

[328] National Science Foundation Act of 1950, sec. 14 (c) (renumbered sec. 15 (c) in 1958).

[329] *First 15 Years*, p. 6.

[330] Ibid., pp. 6-7, 9.

[331] From statements by Mr. Daddario quoted in Schaffter, pp. 220-222.

[332] Schaffter, pp. 226-227.

dations had excluded them. Sensitive to this history and to other pressures, NSF had used its original authority "to initiate and support basic scientific research . . . in . . . other sciences"[333] with great caution. Certain social science research projects which were closely related to the life sciences and physical sciences were started with funding of $20,000 in 1954. Support of this type of research had grown to over $14 million, or 5.7 percent of NSF's total budget, by 1968. This important field now represents 6.1 percent of NSF's total program expenditures.

In its first year, 1951, NSF had a total budget of $225,000, and it did not administer any funds for research. The following year it reported basic research obligations of $869,000 in the life sciences and $375,000 in the physical sciences.[334] In 1968, just before the new legislation, NSF obligations were reported as $257.4 million for research, of which $251.6 million was for basic research. The small amount of applied research was divided among several fields, chiefly the life sciences and the social sciences.[335] NSF's applied research has grown significantly in response to the 1968 mandate. Estimated total research obligations for 1977 are $674.5 million, of which $605.8 million is for basic research. The distribution of funds for the 1977 basic research program according to fields of science is $164.6 million for the physical sciences, $138.6 million for the environmental sciences, $113.4 million for the life sciences, $68.2 million for engineering, $37.4 million for mathematics, $37.1 million for the social sciences, $10.0 million for psychology, and $36.5 million for other sciences.[336]

Department of Transportation

The Department of Transportation (DOT) reports a small amount of basic research in its section of Part I. This research may be considered basic in a broad sense but not within NSF's definition of basic research and hence is not reported for inclusion as basic research in the *Federal Funds* series. Historically, there have been some misleading fluctuations in the *Federal Funds* data, which DOT ascribes to changing definitions of basic research within and among agencies.

When it was under the Treasury Department, the Coast Guard (CG) reported some basic research from 1961 on. The amount steadily increased from $133,000 in 1961 to $812,000 in 1965. In 1966, and for three quarters of 1967, the CG was still under Treasury but the data in *Federal Funds* are tabulated under DOT and the obligations reported for basic research are $4.5 million and $6.0 million. For the next 3 years, under DOT, the reported figures are even higher, reaching $11.1 million in 1970, but then plunging to $43,000 in 1971 and finally disappearing altogether in 1976. The Science Advisor to the Commandant confirms that the present report of no basic research is correct, and there is no evidence that the actual program fluctuated greatly.

Similarly, the Bureau of Public Roads (BPR) before its transfer to DOT had a modest program of basic research under Commerce, indicated by $59,000 in obligations reported for 1952 in engineering and social sciences. This grew rather gradually to $743,000 in 1965. Commerce planned $1.3 million and $1.7 million for the following 2 years; although all but the last quarters were actually under Commerce, the figures tabulated under DOT as actual obligations for these years are $2.0 million and $6.4 million. BPR's reported obligations for basic research also tumbled from $7.4 million in 1970 to $134,000 in 1971, and to zero in 1973. The same sharp drop is found in the figures reported for the Federal Highway Administration (FHA), which started at $6.4 million for basic research in 1967, grew slightly to $7.4 million in 1970, dropped to $134,000 in 1971, and reached zero in 1973. On the other hand, some basic research was started in the Secretary's office at the same time research in the CG, BPR, and FHA was declining. This is demonstrated by reported obligations of $153,000 for the first year, 1971, and $100,000 in the final year, 1974. This research was all in engineering except for the first year when several other fields were also included.[337]

In 1972 DOT started a university research program. Discussions with staff members in the University Research Office of DOT indicate that this program has not had a large basic research component. It was used first to make university expertise available to the States to help them do a better job of planning their transportation systems. Recently it has concentrated more on transportation technology, and some of this work is relatively long-range and might be included in the work considered basic in a broad sense, as referred to by the Department in the DOT section of Part I.

[333] Sec. 3 (a) (2), National Science Foundation Act of 1950.

[334] *Federal Funds*, Vol. I, Table A; Vol. II, Table B-7.

[335] *Federal Funds*, Vol. XVIII, NSF 69-31, Table C-14, C-33, and C-52.

[336] *Federal Funds*, Vol. XXVI, NSF 77-317, Tables C-15 and C-34.

[337] *Federal Funds*, Vols. II-XXIV.

Department of Justice

Although the office of Attorney General dates back to 1789, the Department of Justice was not founded until 1870. The first record of any basic research support by the Department of Justice is that of fiscal year 1968, when the Bureau of Prisons designated $6,000 for research in mathematics and $34,000 for research in the social sciences. This was the year after the Institute for Defense Analyses (IDA) submitted a report to the President's Commission on Law Enforcement and Administration of Justice. This report contains the following statement concerning research:

> The natural sciences and technology have long helped the police to solve crimes. Scientists and engineers have had very little impact, however, on the overall operations of the criminal justice system and its principal components: police, courts, and corrections. More than 200,000 scientists and engineers have applied themselves to solving military problems and hundreds of thousands more to innovation in other areas of modern life, but only a handful are working to control the crimes that injure or frighten millions of Americans each year.

IDA recommended, in part:

> Probably the most important single mechanism for bringing the resources of science and technology to bear on the problems of crime would be the establishment of a major prestigious science and technology research program within a research institute. The program would create interdisciplinary teams of mathematicians, computer scientists, electronics engineers, physicists, biologists, and other natural scientists, and would require psychologists, sociologists, economists, and lawyers on these teams. The institute and the program must be significant enough to attract the best scientists available, and to this end, the director of this institute must himself have a background in science and technology or have the respect of scientists.[338]

The Commission then recommended that, "A major scientific and technological research program within a research institute should be created and supported by the Federal Government."[339] It also stated that a National Foundation for Criminal Research should be established as an independent agency, commenting that, "there is too little research now being done in this field and very few skilled researchers to do it."[340] The Commission also recommended the creation of the Law Enforcement Assistance Administration (LEAA) but indicated caution about trying to do too much all at once, stating that perhaps the Foundation should be delayed until after LEAA was operating.

LEAA was established by the so-called 1968 Safe Streets Act; an amendment to this act created the National Institute of Law Enforcement and Criminal Justice (NILECJ) under LEAA; since its creation, all reported funding for Justice Department research has been designated for the Institute.

The first confirmed director of LEAA, Henry Ruth, felt strongly that the mood of Congress was anti-research.[341] Furthermore, the administrative procedures of LEAA allowed him almost no freedom to plan a research program, regardless of his experience and qualifications.[342] NILECJ moved into applied research rather rapidly, but the first funding for basic research was not reported until 1973—$2.1 million, almost all in social sciences.[343] The latest published estimate of the Institute's 1977 basic research obligations shows that $10.0 million has been designated—all of it for research in the social sciences.[344] All Institute research is extramural (the 11 percent reported as intramural represents the cost of administering the program).[345] The program was rather severely criticized by the Committee on Research in Law Enforcement and Criminal Justice of the National Research Council.[346] This matter was extensively reviewed by Congress in 1977, and the Director has since expressed confidence that the situation will improve rapidly.[347]

Other Executive Agencies

A number of agencies have reported either relatively small or intermittent basic research programs and hence were not requested to contribute to Part I of this report. The **Treasury Department,** for example, has been the agent of the Govern-

[338]Institute for Defense Analyses, *Task Force Report: Science and Technology* (GPO: Washington, D.C., 1967), pp. 1-82.

[339]President's Commission on Law Enforcement and Administration of Justice, *The Challenge of Crime in a Free Society* (GPO: Washington, D.C., 1967), p. 271.

[340]Ibid., p. 277.

[341]National Research Council, *Understanding Crime* (NAS: Washington, D.C., 1977), pp. 17-18.

[342]Ibid., p. 18.

[343]*Federal Funds*, Vol. XXIII, NSF 74-320A, Table C-33.

[344]*Federal Funds*, Vol. XXVI, NSF 77-317, Table C-34.

[345]Ibid., Table C-30.

[346]National Research Council, op. cit., pp. 4-6.

[347]Informal communication to NSB staff, 1977.

ment chosen to manage many research programs not otherwise related to Treasury responsibilities. In fact, perhaps the earliest Federal grant to a private body to conduct research was that which Treasury made to the Franklin Institute in 1830 to pay for the materials necessary for experiments to determine the cause of boiler explosions. In 1954 and 1955 Treasury reported as much as $1.7 million and $1.5 million, respectively, for basic research in the physical sciences supported by the Bureau of Engraving and Printing.

In addition to the Treasury Department, numerous other agencies have supported basic research. The **Office of Science and Technology,** for example, abolished June 30, 1973, supported basic research in a variety of scientific fields from 1966 to 1972 with annual obligations from $300,000 to $408,000. Similarly, the **Office of Telecommunications Policy,** eliminated in 1977, supported basic research in several fields during the period from 1975 to 1977 with annual obligations of $356,000, $390,000 and $190,000, respectively. The **Office of Economic Opportunity** also had a substantial program of basic research in the social sciences from 1966 until many of its functions were transferred to other agencies in 1973. This program began with $5.0 million in 1966, reached a peak of $8.7 million in 1968, and was phased out with $4.2 million in 1972 and $865,000 in 1973. None of its successor agencies reports obligations which would reflect their having picked up the program.

Other independent agencies have supported relatively small basic research programs. **ACTION,** responsible for the Peace Corps and Vista among other programs, supported basic research in the social sciences from 1975 to 1977 with reported obligations of $115,000, $32,000, and $92,000, respectively. The **Federal Trade Commission** reported $135,000 in basic research obligations for 1962 and $300,000 in 1976, with $355,000 estimated for 1977; all obligations are for research in the social sciences. **The General Services Administration (GSA)** reported basic research obligations starting in 1973 with $48,000 for research in engineering. This program peaked in 1974 with $510,000; in 1975 basic engineering research obligations were $224,000. Basic research classified as "other sciences" has been supported with funds amounting to $60-$65,000 a year. The **Interstate Commerce Commission** reported obligations for basic research in the social sciences from 1952 to 1954 at $9,000 per year. The **National Foundation on the Arts and the Humanities** reports no basic research but, "It makes grants in support of research productive of humanistic knowledge. . . ." The **Nuclear Regulatory Commission** likewise reports no basic research, but some of what was done by its predecessor, the AEC, and which seems to still be going on, might be interpreted by some as mission-oriented basic research, especially in fluid dynamics.

The Small Business Administration reported obligations of $251,000 for basic research in social sciences in 1965. The **Tennessee Valley Authority** reported $385,000 in obligations for basic research in the life sciences in 1952. The **U. S. Arms Control and Disarmament Agency** had a 3-year program of basic research in the mathematical, engineering, and social sciences from 1966 to 1968 at an average obligation level of $675,000 per year. The **United States Information Agency** reported $21,000 for support of basic research in 1957; the research may have been in the physical sciences although the tables do not clearly indicate the field. Since 1955, the **United States Civil Service Commission** has had a relatively small but consistent program of basic research, probably in psychology. From 1956 to 1958, the reported obligations were tabulated under social sciences, psychology not being recognized in the tables as a separate field until 1959. Annual obligations grew slowly to $46,000 in 1969 and more rapidly after that to a peak of $559,000 in 1975. The estimate for 1977 is $227,000.[348]

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[348] All obligations quoted for "Other Executive Agencies" are taken from *Federal Funds*, Vols. II-XXVI.

APPENDICES

APPENDICES

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Appendix A

Resolution Adopted by the National Science Board at Its 167th Meeting on October 18, 1974

Whereas, Section 3(d) of the National Science Foundation Act of 1950 as amended states that: "The Board and the Director shall recommend and encourage the pursuit of national policies for the promotion of basic research and education in the sciences."; and

Whereas, Section 3(a)(5) of the Act authorizes and directs the National Science Foundation to evaluate the status and needs of the various sciences as evidenced by programs, projects, and studies undertaken by agencies of the Federal Government, by individuals, and by public and private research groups, employing by grant or contract such consulting services as it may deem necessary for the purpose of such evaluations, and to take into consideration the results of such evaluations in correlating the research and educational programs undertaken or supported by the Foundation with programs, projects, and studies undertaken by agencies of the Federal Government, by individuals, and by public and private research groups, and

Whereas, the national welfare requires and it has been a long standing matter of national policy that mission agencies pursue strong programs of basic research appropriate for their missions; and

Whereas, in recent years some Federal agencies have significantly reduced their efforts in basic research relevant to their missions; and

Whereas, shifts in other agencies' support of basic research affect the National Science Foundation's capability to fulfill one of its roles to ensure the adequacy of the Nation's research effort;

Therefore, be it RESOLVED, That:

The National Science Board encourages mission agencies of the Federal Government to maintain strong basic research programs in areas that have the potential of contributing to their mission objectives over the long term;

The National Science Foundation shall develop information on the interrelationships of NSF basic research programs with the basic research activities of other Federal agencies for use in evaluating the status and needs of the various sciences, in correlating the basic research programs undertaken and supported by the Foundation with related programs undertaken by other agencies of the Federal Government, and in recommending to applicable agencies, to the Administration, and to the National Science Board those areas that require strengthening;

To assist the National Science Foundation in coordinating and correlating its basic research programs with those of other agencies, the National Science Board shall develop and promulgate a general policy statement pertaining to Foundation assumption of management and/or support responsibilities for major program activities or projects for which support has been terminated or significantly reduced by other Federal agencies due to considerations of mission relevancy or budgetary priorities;

The Director of the National Science Foundation is urged to hold a series of discussions with the secretaries and/or other appropriate senior officials of selected mission agencies of the Federal Government for the purposes of discussing the need for mission agencies to maintain strong basic research programs appropriate to their missions and the benefits that are likely to accrue from such programs over the long term. These discussions should also focus on the nature and scope of current and planned mission agency basic research efforts and on the areas of research that are likely to be of significance to mission agency programs. These discussions should be carried out with a view to strengthening the overall Federal basic research posture and to identifying areas of need in the various science fields;

The Director of the National Science Foundation is urged to take an active role in promoting basic research within the Executive Branch, including assisting other Federal agencies as appropriate in initiating basic research programs where none now exists and where the potential for long term benefits to the agencies' missions from such programs is greatest; and through discussions with the mission agencies and the Office of Management and Budget ascertain the status of Federal programs of basic research.

Appendix B

OMB Memorandum to the Heads of Executive Departments and Agencies on Funding of Basic Research, August 15, 1977

The President has expressed his interest in having Federal departments and agencies examine their research and development programs to assure an appropriate balance between basic or long-term research and shorter-term applied research and development. The President is particularly concerned with the identification of critical problems currently or potentially faced by the Federal Government where basic or long-term research could assist in carrying out Federal responsibilities more effectively or where such research would provide a better basis for decision-making.

An example would be the recent efforts to strengthen the basic research program of the Department of Agriculture which could lead to breakthroughs in a number of problem areas, including reducing the vulnerability of crops to insects and diseases through genetic engineering. Another example would be research to improve our understanding of scientific phenomena that underlie various regulatory decisions of the Federal Government (e.g., the setting of air quality standards).

We are asking that in the context of developing your 1979 budget you identify whether there are specific problems in your area of responsibility that might be better addressed through basic research and then use the results of your review to determine whether available resources can be better applied to basic or long-term research associated with those problems. In so doing, you are urged to look carefully at your existing R&D programs to see whether there are areas where tradeoffs can be made, taking into account, for example, the effectiveness of current R&D efforts, and the need to avoid research, development and demonstration activities that might more appropriately be left to the private sector.

There is a tendency to defer needed basic or long-term research to meet more pressing near-term problems. We urge that in developing budget proposals for your agency you take a balanced view in dealing with your R&D programs and be sensitive to this tendency. Of course, we expect that you will apply the same rigorous zero-base budget review to basic research programs that you are applying to other programs in your agency.

The results of your review should be reported along with the information about R&D and basic research programs which is submitted as a routine part of your agency's budget preparation (section 44 of OMB Circular A-11). The data in that section should be supplemented with a narrative description of the problem areas identified as outlined above, and should identify any changes proposed in your agency's R&D programs to focus agency resources on long-term research related to these problem areas. This approach should obviate the need to make any changes in your current ZBB structure.

Your review should be completed in time to be reflected in your agency's initial budget submission. A report on your review should be submitted to OMB not later than September 30. Your budget submission is expected to be consistent with the amounts and general guidance provided in the policy letter sent to you previously.

Bert Lance
Director

Appendix C

Methodology for Preparation of the Report

The initial step in the process of obtaining information for the report on "Basic Research in the Mission Agencies" was the request to agency officials by Dr. Norman Hackerman, Chairman of the National Science Board, in his letter dated December 10, 1976 (see Exhibit 1). Accompanying the letter as an enclosure was the draft outline of the report, together with a suggested format for Chapter 2, which is now Part I of the printed report (see Exhibit 2). The letter with enclosures was sent to agency officials who had been identified as being responsible for scientific activities in the various mission agencies of the Federal Government. (For list of agency officials to whom the December 10 letter was sent, see Exhibit 3).

The first round of discussions with mission agency contacts, as designated by the recipients of the December 10 letter, was completed by the third week of January 1977. During this round of discussions a set of questions and issues relating to basic research in the mission agencies was given to each agency contact (see Exhibit 4). This set of questions and issues was designed to make more explicit the kinds of information desired for Part I (questions A1-9) and for Chapters 1-9 (questions B1-15).

During the first round of discussions each agency contact was informed that the time limit for submission of material was three months (in effect, by April 15, 1977); that the submission for Part I should be approximately 5,000 words, exclusive of charts, graphs, photographs, tables, etc.; that the Part I submission should be identified by its author(s) or by name of the submitting or approving official. Flexibility was stressed; multiple submissions (of about 5,000 words each) were encouraged in those agencies with substantial basic research programs characterized by organizational diversity and/or subject matter complexity.

A second round of discussions was begun some weeks after the first round had been completed. A number of these involved groups of individuals who were brought together by the responsible agency official to enable them to ask questions relating to the responses being prepared inside the agency. It was emphasized at each meeting that the Board expected to have the report ready for publication in January 1978. The second round of discussions, involving meetings with some 60-70 individuals in the various mission agencies, was essentially completed by the end of March 1977.

The approach outlined above and the material included in Exhibits 1-4 were reviewed and approved by the Board Committee on the Tenth NSB Report at its meetings on August 19, 1976, September 17, 1976, November 19, 1976, February 3, 1977, and March 17, 1977.

Many subsequent discussions were held with agency officials during the period April - December 1977. The last agency submission was received in December 1977.

Exhibit 1 — Letter of Dr. Norman Hackerman (Dec. 10, 1976)

Dear:

At its meeting in October 1974, the National Science Board adopted a resolution encouraging mission agencies of the Federal Government to maintain strong basic research programs in areas that have the potential of contributing to their mission objectives. It was noted at the time that the National Science Foundation should develop information on the basic research activities of Federal agencies for use in evaluating the status and needs of the various sciences, in correlating the basic research programs of the Foundation with those undertaken by other agencies of the Federal Government, and in recommending those areas that require strengthening.

The tenth annual report of the National Science Board, due in January 1978, will focus on the topic: "Basic Research in the Mission Agencies." Although the Board is naturally concerned about the adequacy of basic research support in the United States, it does not wish to take an advocacy position in this report. Rather, the Board wishes to provide an objective assessment of the present status of the basic research which is supported by the Federal Government and carried out in agency laboratories, in universities, in industry, and in nonprofit institutions.

This report will embrace much of the statistical information on basic research support which is submitted annually to the Foundation for incorporation in the Surveys of Science Resources series. However, it is expected that the Board report will go beyond the statistical information so as to enable the Federal agencies to portray, by explanation and example, the significant aspects of their basic research activities and the contributions of these activities to agency objectives, to science, and to the national welfare.

In order to accomplish this purpose, each agency is being asked to provide information to the Foun-

dation that is directly pertinent to its own research programs. This information is to be provided by the appropriate agency official and will be published with his name as author or as approving official.

Dr. H. Guyford Stever, Director, Office of Science and Technology Policy, and Science and Technology Adviser to the President, concurs in the desirability of making the study which will culminate in the tenth Board report.

You may be interested to know that the following Board Members are serving on the Board Committee on Tenth NSB Report:

Dr. Grover E. Murray (Chairman)
University Professor, Texas Tech University Complex

Dr. T. Marshall Hahn, Jr. (Vice Chairman)
President, Georgia-Pacific Corporation

Dr. Lloyd M. Cooke
Corporate Director-Community Affairs
Union Carbide Corporation

Dr. William F. Hueg, Jr.
Deputy Vice President and Dean, Institute of Agriculture, Forestry, and Home Economics
University of Minnesota

I have asked Dr. C. E. Sunderlin of the National Science Board staff to contact you or your designee in the coming weeks for a discussion on the draft outline of the report, copy enclosed, on some of the questions and issues which will arise in the course of its preparation, and on the tentative timetable for submission of material.

It is our earnest hope that the tenth Board report will provide the Federal agencies, the Congress, the scientific community, and the country at large with information which is beneficial to the national welfare.

Sincerely yours,

Norman Hackerman
Chairman

Enclosure (Exhibit 2)

Copies sent to names on attached list (Exhibit 3)

Exhibit 2 — Outline of the 10th National Science Board Report (Dec. 3, 1976)

BASIC RESEARCH IN THE MISSION AGENCIES

1. Introduction
2. The Mission Agencies: A Factual Survey
   (a) Department of Agriculture
   (b) Department of Commerce
   (c) Department of Defense
   (d) Department of Health, Education, and Welfare
   (e) Department of Housing and Urban Development
   (f) Department of the Interior
   (g) Department of Justice
   (h) Department of Labor
   (i) Department of State
   (j) Department of Transportation
   (k) Energy Research and Development Administration
   (l) Environmental Protection Agency
   (m) National Aeronautics and Space Administration
   (n) National Science Foundation*
   (o) Smithsonian Institution*
   (p) Veterans Administration
3. The Mission Agencies: Comparative Analysis and Historical Trends
4. Basic Research in Agency Laboratories and in Federally Funded Research and Development Centers
5. Agency Support of Basic Research in Industry
6. Agency Support of Basic Research in Universities
7. Agency Support of Basic Research by Fields of Science
8. Management of Basic Research in the Mission Agencies
9. Effects of Recent Legislation on Agency Support of Basic Research (e.g., the Mansfield Amendment, OSHA requirements, Arms Control Impact Statement requirements)
10. Barriers to Optimum Support of Basic Research by the Mission Agencies
11. Interagency Coordination of Basic Research
12. Priorities and Gap Areas
13. Summary

Appendices

Suggested Format for Chapter 2

(1) Statement of agency mission(s).
(2) Agency definition of basic research.

*Data included for completeness and for comparison.

(3) Role of basic research in support of agency mission(s).
(4) Significant examples of basic research support (intramural and/or extramural).
(5) Areas of current and future emphasis in support of basic research. (Identification of promising areas that may not be funded.)
(6) Organization and management of scientific activities, including support of basic research.

NOTES:

(a) Time limit for submission: 3 months.
(b) Submissions to be identified by authors or submitting officials.
(c) Statistical data to be furnished to each agency by NSF for FY's 1975, 1976, and 1977.

Exhibit 3—Addresses of Agency Officials (as of December 10, 1976)

Department of Agriculture

Honorable Robert W. Long
Assistant Secretary
Conservation, Research, and Education
Department of Agriculture
Washington, D.C. 20250

Dr. Don A. Paarlberg
Director
Agricultural Economics
Department of Agriculture
Washington, D.C. 20250

Department of Commerce

Honorable Robert M. White
Administrator
National Oceanic and Atmospheric Administration
Department of Commerce
Washington, D.C. 20230

Honorable Betsy Ancker-Johnson
Assistant Secretary for Science and Technology
Department of Commerce
Washington, D.C. 20230

Department of Defense

Honorable Malcolm R. Currie
Director of Defense Research and Engineering
Department of Defense
Washington, D.C. 20301

Honorable Edward A. Miller
Assistant Secretary of the Army (Research and Development)
Department of Defense
Washington, D.C. 20301

Honorable H. Tyler Marcy
Assistant Secretary of the Navy (Research and Development)
Department of Defense
Washington, D.C. 20301

Honorable John J. Martin
Assistant Secretary of the Air Force (Research and Development)
Department of Defense
Washington, D.C. 20301

Department of Health, Education and Welfare

Honorable Theodore Cooper
Assistant Secretary for Health
Department of Health, Education and Welfare
Washington, D.C. 20201

Honorable James D. Isbister
Administrator
Alcohol, Drug Abuse, and Mental Health Administration
Department of Health, Education and Welfare
Washington, D.C. 20201

Honorable Donald S. Fredrickson
Director
National Institutes of Health
Department of Health, Education and Welfare
Washington, D.C. 20201

Honorable Virginia Y. Trotter
Assistant Secretary for Education
Department of Health, Education and Welfare
Washington, D.C. 20201

Department of Housing and Urban Development

Honorable Charles J. Orlebeke
Assistant Secretary for Policy Development and Research
Department of Housing and Urban Development
Washington, D.C. 20410

Department of the Interior

Honorable Nathaniel P. Reed
Assistant Secretary for Fish and Wildlife and Parks
Department of the Interior
Washington, D.C. 20240

Honorable William L. Fisher
Assistant Secretary—Energy and Minerals
Department of the Interior
Washington, D.C. 20240

Honorable Vincent E. McKelvey
Director
U. S. Geological Survey
Department of the Interior
Washington, D.C. 20240

Honorable Jack O. Horton
Assistant Secretary—Land and Water Resources
Department of the Interior
Washington, D.C. 20240

Department of Justice

Honorable Richard W. Velde
Administrator
Law Enforcement Assistance Administration
Department of Justice
Washington, D.C. 20530

Department of Labor

Honorable Bernard E. Delury
Assistant Secretary for Labor-Management Relations and Administrator, Labor-Management Services Administration
Department of Labor
Washington, D.C. 20210

Department of State

Honorable Daniel Parker
Administrator
Agency for International Development
Department of State
Washington, D.C. 20520

Honorable Frederick Irving
Assistant Secretary
Oceans and International Environmental and Scientific Affairs
Department of State
Washington, D.C. 20520

Department of Transportation

Honorable Hamilton Herman
Assistant Secretary for Systems Development and Technology
Department of Transportation
Washington, D.C. 20590

Energy Research and Development Administration

Honorable Robert C. Seamans, Jr.
Administrator
Energy Research and Development Administration
Washington, D.C. 20545

Environmental Protection Agency

Honorable Russell E. Train
Administrator
Environmental Protection Agency
Washington, D.C. 20460

National Aeronautics and Space Administration

Honorable James C. Fletcher
Administrator
National Aeronautics and Space Administration
Washington, D.C. 20546

National Science Foundation

Honorable Richard C. Atkinson
Acting Director
National Science Foundation
Washington, D.C. 20550

Smithsonian Institution

Honorable S. Dillon Ripley
The Secretary
Smithsonian Institution
Washington, D.C. 20560

Veterans Administration

Dr. John D. Chase
Chief Medical Examiner
Department of Medicine and Surgery
Veterans Administration
Washington, D.C. 20420

Exhibit 4—Questions and Issues Relating to Basic Research in the Mission Agencies

A. *Primarily with reference to Chapter 2* (Part I in printed report):
   (1) What is your agency's operating definition (written or implicit) of basic research?
   (2) What are your agency's policies concerning support of basic research?

(3) List the 10 most significant projects involving basic research (intramural and/or extramural) which your agency has carried out in the last 10 years. It would be most helpful, in answering this question, if you would also list the most significant research papers published during the last 10 years by scientists in your agency, together with supporting data from the citation index as evidence of their importance.
(4) List the five most interesting agency projects involving basic research which are currently in progress.
(5) What are your research priorities for the next 3 years? For the next 10 years?
(6) What promising or vital areas of research, not now supported but involving basic research, warrant increased emphasis and support by your agency?
(7) What is the management structure for initiation, review, and evaluation of agency-supported research?
(8) How are decisions made for (a) initiation and conduct of research in agency laboratories and/or (b) support of research by grant or outside contract in industry, in universities, and in nonprofit institutions?
(9) How can support of basic research be explicitly recognized and incorporated into mission agency programs to enable the agency best to accomplish its objectives? For example, what are the mechanisms for initiation and termination of basic research projects? What criteria are used to determine level of support during initial and subsequent phases of a basic research project? How are priorities established for allocation of funds to basic research projects in competition with research and/or development projects? How does your agency prevent near-term programs which are in financial trouble from siphoning funds from the basic research program in order to bail them out?

B. *Primarily with reference to Chapters 3-11* (1-9 in printed report):
(1) Outline the significant trends in conduct and support of basic research in your agency since World War II.
(2) What criteria are used when making a decision to conduct a research project in an agency laboratory rather than to support the project in industry, a university or a nonprofit institution? Do the same criteria apply if the research project is identified as being basic research?
(3) What are the most important factors affecting the quality of the basic research carried on in your laboratories? Assuming that people, money, and facilities are important factors, how does your agency select and/or replenish the people who do your basic research? Do salary levels and Federal regulations enhance or inhibit your ability to select the best people for your basic research projects? Is there a system of incentives and rewards in your agency which is specifically designed to recognize outstanding accomplishments by scientists engaged in basic research? Is obsolescence of equipment and/or facilities an important factor with respect to conduct of basic research in your laboratories?
(4) What are the most important factors affecting the quality of the basic research projects supported by your agency under grant or contract with industry, universities, and nonprofit institutions? How important is the institutional commitment to basic research?
(5) What mechanisms exist for the maintenance of quality standards for the research which is supported by your agency? Does your agency have external review committees to help in the evaluation of the quality of your basic research programs? Are the reports of these external review committees published regularly?
(6) What legislation in the past 8 to 10 years has had a significant impact on your agency support of basic research?
(7) What Federal regulations and policies, if any, impede the conduct and/or support of basic research by your agency?
(8) What changes in Federal regulations and policies would facilitate conduct or support of basic research by your agency?
(9) What barriers exist to optimum support of basic research by your agency?
(10) Does security classification of research projects have a significant impact on the conduct of basic research in your agency laboratories?
(11) What mechanisms exist for interagency consultation and coordination of effort on research projects of mutual interest to your agency and one or more other agencies? Do the same mechanisms apply for basic research projects?
(12) Does the "lead agency" concept work effectively for research projects which are vital to your own ongoing programs as well as to those of other agencies?

(13) What barriers exist to the dissemination of scientific information resulting from basic research conducted or supported by your agency?

(14) Does your agency support research projects in foreign countries? How important is the basic research component, if any, of these projects?

(15) What problems have you identified in connection with international cooperative scientific programs in which your agency was involved? What problems do you foresee in future international research projects?

December 1976

Appendix D

Table C-30.—Federal obligations for basic research, by agency and performer, fiscal year 1977 (est.)

[Thousands of dollars]

Agency and Subdivision	Total	Intramural[1]	Extramural: United States and Territories: Industrial firms	FFRDC's admin. by industrial firms	Universities and colleges	FFRDC's admin. by univs. and colleges	Other nonprofit institutions	FFRDC's admin. by nonprofit institutions	State and local govts.	Foreign
Total, all agencies	$2,754,656	$790,913	$151,671	$49,417	$1,290,153	$315,110	$117,563	$7,194	$14,402	$18,233
Departments										
Agriculture, total	194,007	135,949	130	—	52,940	—	70	—	215	4,703
Agricultural Research Service	115,911	109,539	—	—	1,669	—	—	—	—	4,703
Cooperative State Research Service	48,904	1,864	—	—	46,845	—	—	—	195	—
Economic Research Service	3,930	3,888	—	—	42	—	—	—	—	—
Forest Service	24,787	20,227	130	—	4,340	—	70	—	20	—
Statistical Reporting Service	475	431	—	—	44	—	—	—	—	—
Commerce, total	25,050	19,309	1,580	—	2,772	300	904	—	185	—
Bureau of the Census	200	200	—	—	—	—	—	—	—	—
Economic Development Administration	1,675	84	100	—	402	—	904	—	185	—
Maritime Administration	1,430	29	1,401	—	—	—	—	—	—	—
National Bureau of Standards	6,544	6,014	—	—	530	—	—	—	—	—
National Fire Prevention & Control Admin	3,148	1,332	79	—	1,437	300	—	—	—	—
National Oceanic & Atmos. Administration	11,750	11,347	—	—	403	—	—	—	—	—
Office of Minority Business Enterprise	200	200	—	—	—	—	—	—	—	—
Office of Telecommunications	103	103	—	—	—	—	—	—	—	—
Defense, total	274,668	97,734	54,849	—	112,251	570	5,814	1,188	—	2,262
Department of the Army	40,125	15,562	1,971	—	19,879	—	2,152	—	—	561
Department of the Navy	115,800	44,378	11,708	—	56,305	—	2,384	—	—	1,025
Department of the Air Force	82,600	32,572	26,620	—	22,665	—	101	—	—	642
Defense Agencies	36,143	5,222	14,550	—	13,402	570	1,177	1,188	—	34
Health, Education & Welfare, total	747,114	150,532	866	—	495,576	1,678	80,585	278	12,565	5,034
Alcohol, Drug Abuse, & Mental Health Admin.	60,147	19,030	—	—	31,398	—	5,646	—	2,111	1,962
Health Resources Administration	2,988	733	71	—	1,200	—	894	—	90	—
Health Services Administration	310	310	—	—	—	—	—	—	—	—
National Institute of Education	11,900	2,142	715	—	3,215	—	4,161	—	1,667	—
National Institutes of Health	670,169	127,677	—	—	458,963	1,678	69,804	278	8,697	3,072
Office of the Secretary	1,600	640	80	—	800	—	80	—	—	—

Interior, total	124,633	113,561	1,872	–	8,117	–	–	–	165	918
Bureau of Mines	800	800	–	–	–	–	–	–	–	–
Bureau of Reclamation	70	70	–	–	–	–	–	–	–	–
Geological Survey	106,435	102,208	227	–	4,000	–	–	–	–	–
National Park Service	619	227	–	–	392	–	–	–	–	–
Office of the Secretary	3,116	898	1,000	–	300	–	–	–	–	918
Office of Water Res. & Technology	3,465	530	395	–	2,525	–	–	–	15	–
Fish and Wildlife Service	10,128	8,828	250	–	900	–	–	–	150	–
Justice, total	10,000	1,100	–	–	2,023	–	5,377	1,200	300	–
Law Enforcement Assistance Admin	10,000	1,100	–	–	2,023	–	5,377	1,200	300	–
Labor, total	785	189	–	–	596	–	–	–	–	–
Employment and Training Administration	670	74	–	–	596	–	–	–	–	–
Labor-Management Services Admin	115	115	–	–	–	–	–	–	–	–
Other agencies										
ACTION	92	8	76	–	–	–	8	–	–	–
Civil Service Commission	277	277	–	–	–	–	–	–	–	–
Energy Research & Development Admin	390,686	899	834	47,337	77,003	260,320	888	3,405	–	–
Environmental Protection Agency	21,200	1,060	–	–	19,640	–	500	–	–	–
Federal Trade Commission	355	355	–	–	–	–	–	–	–	–
General Services Administration	65	65	–	–	–	–	–	–	–	–
Library of Congress	150	150	–	–	–	–	–	–	–	–
National Aeronautics & Space Admin	319,694	156,684	83,734	–	66,036	8,271	2,942	760	45	1,222
National Science Foundation	605,821	75,234	7,584	2,080	451,689	43,971	19,879	363	927	4,094
Office of Telecommunications Policy	190	1	146	–	20	–	23	–	–	–
Smithsonian Institution	30,569	28,506	–	–	1,490	–	573	–	–	–
Veterans Administration	9,300	9,300	–	–	–	–	–	–	–	–

[1] Intramural activities cover costs associated with the administration of intramural and extramural programs by Federal personnel, as well as actual intramural performance. For further description see technical notes in *Federal Funds,* cited below.

Source: *Federal Funds for Research, Development, and Other Scientific Activities, FY 1976, 1977, and 1978,* Vol. XXVI (National Science Foundation. Washington, D.C.), NSF 77-317. Hereinafter cited as *Federal Funds.*

Appendix E

Table B-45.—Funds for basic research, applied research, and development, by industry and selected company size group, 1974 and 1975

[Dollars in millions]

Industry and size of company	SIC code	1974 Total	1974 Basic research	1974 Applied research	1974 Development	1975 Total	1975 Basic research	1975 Applied research	1975 Development
Total		$22,399	$677	$4,160	$17,562	$23,540	$702	$4,411	$18,426
Distribution by industry									
Food and kindred products	20	295	22	110	163	324	25	119	180
Textiles and apparel	22,23	69	2	24	43	64	2	22	40
Lumber, wood products, and furniture	24,25	64	na	na	na	68	na	na	na
Paper and allied products	26	237	7	79	151	253	8	84	162
Chemicals and allied products	28	2,377	270	945	1,162	2,650	276	1,031	1,340
Industrial chemicals	281-82	1,320	159	562	600	1,459	157	600	702
Drugs and medicines	283	701	87	266	347	804	97	298	410
Other chemicals	284-89	356	22	113	221	387	23	na	234
Petroleum refining and extraction	29,13	622	33	269	320	700	36	324	339
Rubber products	30	290	4	63	224	283	3	61	219
Stone, clay, and glass products	32	187	12	59	116	186	12	60	114
Primary metals	33	311	9	133	170	365	11	154	199
Ferrous metals and products	331-32,3391,3399	158	na	na	na	178	na	na	na
Nonferrous metals and products	333-36,3392	153	na	na	na	187	na	na	na
Fabricated metal products	34	293	3	62	228	311	5	na	242
Machinery	35	2,484	26	320	2,138	2,658	29	325	2,304
Office, computing, and accounting machines	357	1,546	na	na	na	1,662	na	na	na
Electrical equipment and communication	36,48	5,495	181	851	4,462	5,530	193	866	4,471
Radio and TV receiving equipment	365	51	na	na	na	43	na	na	na
Electronic components	367	450	20	59	371	471	na	69	na
Communication equipment & communication	366,48	2,979	141	465	2,372	2,936	147	421	2,368
Other electrical equipment	361-64,369	2,015	na	na	na	2,081	na	na	na
Motor vehicles and motor vehicles equipment	371	2,394	9	154	2,231	2,339	11	na	na
Other transportation equipment	373-75,379	31	na	na	na	28	na	na	na
Aircraft and missiles	372,19	5,319	51	614	4,653	5,729	47	642	5,042
Professional and scientific instruments	38	989	15	111	863	1,034	14	110	na
Scientific and mechanical measuring instruments	381-82	116	4	15	97	129	na	18	108
Optical, surgical, photographic, and other instruments	383-87	873	11	96	766	906	11	93	na

Other manufacturing industries	21,27,31,39	174	8	40	126	189	8	42	139
Nonmanufacturing industries	07-12,14-17,41-47, 49-67, 739, 807, 891	768	24	305	439	828	22	328	478
Distribution by size of company (based on number of employees)									
1,000 to 9,999		1,318	88	364	866	1,408	81	371	956
10,000 to 24,999		2,367	102	656	1,609	2,511	115	686	1,710
25,000 or more		16,336	405	2,495	13,436	17,151	415	2,660	14,076

na - Not separately available but included in total.

Source: Division of Science Resources Studies, National Science Foundation.

Appendix F

Table B-46.—Funds for basic research, applied research, and development, by industry, source of funds, and selected company size group, 1975

[Dollars in millions]

Industry and size of company	SIC code	Federal Total	Federal Basic research	Federal Applied research	Federal Development	Company Total	Company Basic research	Company Applied research	Company Development
Total	....	$8,765	$154	$1,167	$7,444	$14,776	$548	$3,244	$10,982
Distribution by industry									
Food and kindred products	20	1	na	na	na	323	na	na	na
Textiles and apparel	22,23	na	0	na	na	na	na	na	na
Lumber, wood products, and furniture	24,25	na	0	0	na	na	na	na	na
Paper and allied products	26	na	0	na	na	na	na	na	r.a
Chemicals and allied products	28	240	53	83	103	2,410	223	946	1,242
Industrial chemicals	281-82	227	na	na	96	1,232	na	na	606
Drugs and medicines	283	na	na	na	na	na	na	na	na
Other chemicals	284-89	na	0	na	na	na	23	na	na
Petroleum refining and extraction	29,13	30	na	23	na	669	na	301	na
Rubber products	30	na	0	na	na	na	na	na	na
Stone, clay, and glass products	32	1	0	1	1	184	12	59	113
Primary metals	33	10	na	4	na	356	na	151	na
Ferrous metals and products	331-32,3391,3399	na	na	na	na	na	na	na	na
Nonferrous metals and products	333-36,3392	na	na	na	na	na	na	na	na
Fabricated metal products	34	15	na	na	14	296	na	na	227
Machinery	35	373	na	na	259	2,286	na	na	2,044
Office computing and accounting machines	357	na	na	na	na	na	na	na	na
Electrical equipment and communication	36,48	2,515	66	296	2,152	3,016	126	573	2,317
Radio and TV receiving equipment	365	na	na	na	na	na	na	na	na
Electronic components	367	218	na	na	na	253	na	na	na
Communication equipment & communication	366,48	1,285	44	110	1,130	1,651	103	312	1,236
Other electrical equipment	361-64,369	na	na	na	na	na	na	na	na
Motor vehicles and motor vehicles equipment	371	335	na	na	na	2,003	na	na	na
Other transportation equipment	373-75,379	na	na	0	na	na	na	na	na
Aircraft and missiles	372,19	4,529	15	398	4,116	1,200	32	244	924
Professional and scientific instruments	38	181	2	9	na	854	12	101	na
Scientific and mechanical measuring instruments	381-82	26	na	na	21	104	na	na	88
Optical, surgical, photographic, and other instruments	383-87	155	na	na	na	750	na	na	na

Other manufacturing industries	21,27,31,39	na	na	na	na	na	na	na	na
Nonmanufacturing industries	07-12,14-17,41-47, 49-67,739,807,891	501	12	219	270	327	10	105	212
Distribution by size of company (based on number of employees)									
1,000 to 9,999		252	10	26	215	1,156	71	345	741
10,000 to 24,999		423	23	51	349	2,088	92	636	1,360
25,000 or more		7,294	91	829	6,374	9,856	323	1,829	7,704

na - Not separately available but included in total.

Source: Division of Science Resources Studies, National Science Foundation.

Appendix G

Table C-8.—Federal obligations for total research and development, by agency and performer, fiscal year 1977 (est.)

[Millions of dollars]

Agency and Subdivision	Total	Intra-mural[1]	Extramural: United States and Territories: Industrial firms	FFRDC's admin. by indus-trial firms	Univer-sities and colleges	FFRDC's admin. by univs. and colleges	Other non-profit institu-tions	FFRDC's admin. by non-profit insti-tutions	State and local govts.	Foreign
Total, all agencies	$24,465.3	$6,467.0	$11,402.2	$1,061.5	$2,851.1	$1,194.6	$768.7	$252.6	$365.3	$102.2
Departments										
Agriculture, total	525.3	381.2	.3	—	133.8	—	.1	.1	.7	9.1
Agricultural Research Service	276.0	262.7	—	—	4.1	—	—	—	—	9.1
Cooperative State Research Service	128.7	4.9	—	—	123.3	—	—	—	.5	—
Economic Research Service	26.2	25.9	—	—	.3	—	—	—	—	—
Farmer Cooperative Service	1.3	1.3	—	—	*	—	—	—	—	—
Forest Service	90.9	84.3	.3	—	6.0	—	.1	.1	.2	—
Statistical Reporting Service	2.1	1.9	—	—	.2	—	—	—	—	—
Commerce, total	247.4	165.2	25.7	—	31.4	1.1	8.6	.4	14.8	.2
Bureau of the Census	2.7	2.5	—	—	.2	—	—	—	—	—
Economic Development Administration	14.6	.4	.5	—	3.0	—	4.7	—	6.0	—
Maritime Administration	17.9	2.0	14.1	—	.8	—	.5	.3	.3	—
National Bureau of Standards	53.9	53.0	.1	—	.6	—	.2	—	—	.1
National Fire Prevention & Control Admin.	7.0	3.3	1.0	—	1.8	.3	.3	*	.4	—
National Oceanic & Atmos Admin	147.9	101.9	9.9	—	25.0	.8	1.7	.1	8.3	.2
Office of Minority Business Enterprises	2.0	.6	.1	—	—	—	1.3	—	—	—
Office of Telecommunications	1.0	1.0	—	—	—	—	—	—	—	—
Patent & Trademark Office	.4	.4	—	—	—	—	—	—	—	—
Defense, total	11,171.8	3,120.0	7,248.6	115.6	245.3	154.9	109.9	159.2	—	18.2
Department of the Army	2,495.6	906.0	1,509.4	.2	43.3	12.5	16.4	4.0	—	4.0
Department of the Navy	2,871.6	1,054.4	2,479.3	115.1	66.5	90.4	50.8	4.7	—	10.3
Department of the Air Force	4,091.1	921.6	2,908.1	—	84.5	29.5	11.6	132.2	—	3.6
Defense Agencies	675.0	203.1	350.7	.4	50.9	22.5	30.9	16.2	—	.2
Departmentwide Funds	.9	.1	.3	*	.1	—	.2	.1	—	—
Director of Test & Evaluation, Defense	37.6	34.8	.7	—	—	—	—	2.0	—	—

Health, Education, & Welfare, total	2,959.5	546.9	161.4	40.2	1,506.4	6.8	414.5	3.2	238.0	42.1
Alcohol, Drug Abuse & Mental Health	155.0	28.2	7.1	—	85.1	—	20.9	—	11.1	2.5
Center for Disease Control	60.4	42.0	3.3	—	5.0	—	5.9	—	.1	4.1
Food and Drug Administration	42.8	26.3	3.3	—	8.2	—	1.4	—	1.8	1.8
Health Resources Administration	37.0	9.3	.7	—	17.0	—	8.9	—	.9	.1
Health Services Administration	21.4	5.7	—	—	7.4	—	2.6	—	.8	4.9
National Institute of Education	85.7	15.4	5.4	—	22.5	—	29.4	—	12.7	.2
National Institutes of Health	2,233.9	404.3	112.5	40.2	1,297.7	6.6	307.4	3.2	38.4	23.5
Office of Education	174.7	.3	9.1	—	24.8	.1	6.5	—	133.9	—
Office of Human Development	78.1	4.6	7.9	—	32.1	—	22.1	—	6.3	5.0
Office of Ass't Secretary for Education	1.0	.1	—	—	—	—	1.0	—	—	—
Office of the Secretary	20.0	1.2	2.8	—	1.5	—	3.9	—	10.5	—
Social and Rehabilitation Service	29.3	.8	2.7	—	2.2	—	4.2	—	19.5	—
Social Security Administration	20.1	8.7	6.6	—	2.8	—	—	—	2.1	—
Housing & Urban Development	62.7	13.9	22.1	—	2.8	—	15.7	—	8.1	—
Interior, total	348.4	235.6	80.7	—	27.4	.7	—	.2	1.1	2.7
Bonneville Power Administration	5.8	2.8	2.9	—	.1	—	—	—	—	—
Bureau of Land Management	.9	.5	—	—	.5	—	—	—	—	—
Bureau of Mines	145.1	75.1	61.0	—	8.0	.7	—	.2	.1	—
Bureau of Outdoor Recreation	*	*	—	—	—	—	—	—	—	—
Bureau of Reclamation	10.3	5.2	3.1	—	1.4	—	—	—	.6	—
Geological Survey	130.8	124.1	2.4	—	4.1	—	—	—	.2	—
National Park Service	9.9	5.0	.4	—	4.5	—	—	—	*	—
Office of the Secretary	4.9	.9	1.0	—	.3	—	—	—	—	2.7
Office of Water Res. and Technology	19.5	2.4	9.6	—	7.5	—	—	—	.1	—
Fish and Wildlife Service	21.1	19.8	.3	—	.9	—	—	—	.2	—
Justice, total	45.0	7.4	5.4	—	5.7	—	19.9	3.7	2.8	—
Bureau of Prisons	1.3	.7	*	—	.4	—	.2	—	*	—
Drug Enforcement Administration	6.5	1.2	3.5	—	.3	—	.5	1.0	—	—
Federal Bureau of Investigation	1.4	.2	1.2	—	—	—	—	—	—	—
Immigration & Naturalization Service	.8	.1	.7	—	—	—	—	—	—	—
Law Enforcement Assistance Admin	35.0	5.3	—	—	5.0	—	19.2	2.7	2.8	—
Labor, total	34.6	13.8	7.3	—	5.7	.1	5.6	—	2.0	—
Bureau of Labor Statistics	1.4	1.4	—	—	—	—	—	—	—	—
Employment and Training Administration	19.1	4.5	3.2	—	4.4	—	5.1	—	2.0	—
Employment Standards Administration	5.5	5.5	—	—	—	—	—	—	—	—
Labor-Management Services Administration	2.9	1.0	1.1	—	.5	—	.3	—	—	—
Occupational Safety & Health Admin	3.3	.5	2.8	—	—	—	—	—	—	—
Office of the Secretary	2.3	.9	.2	—	.8	.1	.3	—	—	—
State, total	46.2	9.4	1.2	—	21.3	*	8.7	—	—	5.5
Departmental Funds	1.6	.3	.3	—	.5	*	.4	—	—	—
Agency for International Development	44.6	9.2	.9	—	20.9	—	8.2	—	—	5.5

Table C-8.—Continued

Federal obligations for total research and development, by agency and performer, fiscal year 1977 (est.)

[Millions of dollars]

Agency and Subdivision	Total	Intra-mural	Extramural							
			United States and Territories							
			Industrial firms	FFRDC's admin. by indus-trial firms	Univer-sities and colleges	FFRDC's admin. by univs. and colleges	Other non-profit institu-tions	FFRDC's admin. by non-profit insti-tutions	State and local govts.	Foreign
Transportation, total	407.4	76.3	221.4	—	23.4	3.0	8.9	12.8	61.4	.1
Federal Aviation Administration	117.5	26.1	76.7	—	1.3	1.7	—	11.7	—	—
Federal Highway Administration	54.4	.7	12.0	—	11.7	—	.5	—	29.5	—
Federal Railroad Administration	61.7	19.9	37.1	—	1.3	—	.6	1.1	1.5	.1
Highway Traffic Safety Administration	58.9	2.8	31.7	—	3.0	—	6.3	—	15.2	—
Office of the Secretary	33.1	13.4	13.0	—	3.5	1.1	.8	—	1.3	—
Coast Guard	22.3	5.2	15.8	—	.6	.2	.5	—	—	—
Urban Mass Transportation Admin	59.5	8.1	35.2	—	2.0	*	.3	—	13.9	—
Treasury, total	5.3	3.8	.2	—	.1	—	—	1.2	—	—
Bureau of Alcohol, Tobacco, & Firearms	1.3	.1	—	—	—	—	—	1.2	—	—
Bureau of Engraving and Printing	2.8	2.8	—	—	—	—	—	—	—	—
Customs Service	1.2	.8	.2	—	.1	—	—	*	—	—
Other agencies										
ACTION	.3	*	.1	—	—	—	.2	—	—	—
Adv. Comm. on Intergovernmental Relations	1.2	1.2	—	—	—	—	—	—	—	—
Appalachian Regional Commission	.8	*	.8	—	*	—	—	—	*	—
Civil Aeronautics Board	.5	.5	—	—	—	—	—	—	—	—
Civil Service Commission	3.8	2.3	—	—	—	—	—	—	1.5	—
Community Services Administration	19.0	1.0	—	—	—	—	18.0	—	—	—
Consumer Product Safety Commission	7.2	2.6	2.3	—	.1	—	1.8	—	.3	—
Energy Research & Development Admin	3,609.8	256.7	1,323.7	833.0	189.7	882.3	48.5	62.1	3.7	10.2
Environmental Protection Agency	361.4	151.9	112.0	—	42.0	—	24.0	1.5	24.0	6.0
Federal Communications Commission	2.1	1.5	.5	—	—	—	—	—	—	—
Federal Energy Administration	6.1	.8	4.8	—	.2	.2	—	.1	—	—
Federal Home Loan Bank Board	1.0	.9	—	—	.1	—	—	—	—	—
Federal Trade Commission	1.1	1.1	—	—	—	—	—	—	—	—
General Services Administration	1.4	.2	1.2	—	—	—	.1	—	—	—
Interstate Commerce Commission	.6	.1	.4	—	.1	—	—	—	—	—
Library of Congress	3.1	3.0	.1	—	—	—	—	—	—	—
National Aeronautics & Space Admin	3,609.8	1,220.8	2,154.6	—	117.0	82.7	29.7	2.6	.5	1.8
National Science Foundation	686.2	81.3	17.9	2.4	492.3	45.7	33.8	.7	6.0	6.1
Nuclear Regulatory Commission	113.9	8.9	7.1	70.0	3.4	17.1	2.5	4.5	.3	—

Office of Telecommunications Policy	3.5	3.0	.4	–	.1	–	.1	–	–	–
Small Business Administration	1.0	.9	.1	–	–	–	–	–	–	–
Smithsonian Institution	30.6	28.5	–	–	1.5	–	.6	–	–	–
Tennessee Valley Authority	31.7	14.6	–	–	.1	–	16.9	–	–	–
Arms Control & Disarmament Agency	2.4	.3	.9	.1	.1	*	.7	.2	–	–
U.S. Information Agency	.1	.1	–	–	–	–	–	–	–	–
International Trade Commission	2.8	2.8	–	–	–	–	–	–	–	–
Veterans Administration	110.4	108.2	.8	–	1.3	–	–	–	–	–

[1]Intramural activities cover costs associated with the administration of intramural and extramural programs by Federal personnel, as well as actual intramural performance. For further description, see technical notes in *Federal Funds,* cited below.

*Indicates amount less than $50,000.

Source: *Federal Funds* (see footnote, Appendix D, Table C-30).

Appendix H

Table C-32.—Federal obligations for basic research, by detailed field of science, fiscal years 1976, 1977, and 1978

[Thousands of dollars]

Field of science	*Actual, 1976*	*1977 (est.)*	*1978 (est.)*
Total, all fields	$2,425,486	$2,754,656	$3,011,826
Life sciences, total	877,685	1,007,063	1,058,312
Biological	707,592	818,185	860,003
Clinical medical	27,906	28,738	32,365
Other medical sciences	118,665	136,420	142,072
Life sciences, NEC	23,522	23,720	23,872
Psychology, total	43,672	52,629	57,453
Biological aspects	24,957	28,672	29,887
Social aspects	16,911	20,359	22,643
Psychological sciences, NEC	1,804	3,598	4,923
Physical sciences, total	721,557	806,278	910,724
Astronomy	158,909	179,583	219,508
Chemistry	175,061	202,516	222,073
Physics	382,817	416,368	460,430
Physical sciences, NEC	4,770	7,811	8,713
Environmental sciences, total	354,628	393,598	438,055
Atmospheric sciences	119,088	127,514	132,290
Geological sciences	140,265	155,435	183,823
Oceanography	87,242	100,266	109,749
Environmental sciences, NEC	8,033	10,383	12,193
Mathematics & computer sciences, total	70,155	79,388	87,763
Mathematics	39,047	46,362	52,245
Computer sciences	27,912	29,560	32,067
Mathematics & computer sciences, NEC	3,196	3,466	3,451
Engineering, total	239,955	267,772	297,140
Aeronautical	29,797	29,716	34,488
Astronautical	11,529	11,786	13,008
Chemical	12,720	15,087	16,475
Civil	7,685	7,294	7,928
Electrical	43,039	46,624	54,602
Mechanical	14,854	18,902	19,914
Metallurgy & materials	97,429	113,916	121,118
Engineering, NEC	22,902	24,447	29,607
Social sciences, total	85,240	101,972	113,380
Anthropology	6,421	8,360	10,269
Economics	25,634	27,828	28,738
Political science	2,999	2,564	2,988
Sociology	16,478	21,292	18,862
Social sciences, NEC	33,708	41,928	52,523
Other sciences, NEC	32,594	45,956	48,999

Source: *Federal Funds* (See footnote Appendix D, Table C-30).

Appendix I

Table C-34.—Federal obligations for basic research, by agency and field of science, fiscal year 1977 (est.)

[Thousands of dollars]

Agency and subdivision	*Total*	*Life sciences*	*Psychology*	*Physical sciences*	*Environmental sciences*	*Mathematics and computer sciences*	*Engineering*	*Social sciences*	*Other sciences NEC*
Total, all agencies	$2,754,656	$1,007,063	$52,629	$806,278	$393,598	$79,388	$267,772	$101,972	$45,956
Departments									
Agriculture, total	194,007	137,874	25	24,468	3,685	1,495	10,740	15,720	–
Agricultural Research Service	115,911	86,795	–	19,867	1,321	301	7,279	348	–
Cooperative State Research Service	48,904	33,604	–	2,445	306	–	1,676	10,873	–
Economic Research Service	3,930	–	–	–	–	–	–	3,930	–
Forest Service	24,787	17,475	25	2,156	2,058	719	1,785	569	–
Statistical Reporting Service	475	–	–	–	–	475	–	–	–
Commerce, total	25,050	–	45	5,374	11,750	155	2,703	1,875	3,148
Bureau of the Census	200	–	45	–	–	155	–	–	–
Economic Development Administration	1,675	–	–	–	–	–	–	1,675	–
Maritime Administration	1,430	–	–	–	–	–	1,430	–	–
National Bureau of Standards	6,544	–	–	5,374	–	–	1,170	–	–
National Fire Prevention & Control Administration	3,148	–	–	–	–	–	–	–	3,148
National Oceanic & Atmos Admin	11,750	–	–	–	11,750	–	–	–	–
Office of Minority Business Enterprise	200	–	–	–	–	–	–	200	–
Office of Telecommunications	103	–	–	–	–	–	103	–	–
Defense, total	274,668	30,533	11,266	58,763	64,200	25,500	81,794	1,471	1,141
Department of the Army	40,125	13,710	2,820	5,656	4,954	3,119	9,747	119	–
Department of the Navy	115,800	12,922	2,705	29,889	42,704	8,997	17,231	1,352	–
Dept of the Air Force	82,600	3,158	2,915	19,622	16,382	7,980	32,543	–	–
Defense Agencies	36,143	743	2,826	3,596	160	5,404	22,273	–	1,141
Health, Education & Welfare, total	747,114	641,886	29,065	38,318	–	3,616	6,143	23,798	4,288
Alcohol, Drug Abuse, & Mental Health Admin	60,147	33,937	18,525	37	–	383	–	6,922	343
Health Resources Admin	2,988	–	–	–	–	–	–	2,988	–
Health Services Admin	310	310	–	–	–	–	–	–	–
National Institute of Education	11,900	–	–	–	–	–	–	11,900	–
National Institutes of Health	670,169	607,639	10,540	38,281	–	3,233	6,143	388	3,945
Office of the Secretary	1,600	–	–	–	–	–	–	1,600	–
Interior, total	124,633	11,035	–	7,814	100,472	1,100	3,523	514	175
Bureau of Mines	800	–	–	680	–	–	120	–	–
Bureau of Reclamation	70	–	–	–	–	–	70	–	–
Geological Survey	106,435	–	–	6,871	98,477	1,087	–	–	–
National Park Service	619	451	–	–	49	–	–	119	–
Office of the Secretary	3,116	–	–	–	630	–	2,486	–	–
Office of Water Res and Technology	3,465	456	–	263	1,316	13	847	395	175
U.S. Fish and Wildlife Service	10,128	10,128	–	–	–	–	–	–	–
Justice, total	10,000	–	–	–	–	–	–	10,000	–
Law Enforcement Asst Admin	10,000	–	–	–	–	–	–	10,000	–

Table C-34.—Continued

Federal obligations for basic research, by agency and field of science, fiscal year 1977 (est.)

[Thousands of dollars]

Agency and subdivision	*Total*	*Life sciences*	*Psy-chology*	*Physical sciences*	*Environ-mental sciences*	*Mathe-matics and computer sciences*	*Engi-neering*	*Social sciences*	*Other sciences NEC*
Labor, total	785	–	34	–	–	–	–	751	–
Employment & Training Admin	670	–	34	–	–	–	–	636	–
Labor-Mgt Services Admin	115	–	–	–	–	–	–	115	–
Other agencies									
ACTION	92	–	–	–	–	–	–	92	–
Civil Service Commission	277	–	277	–	–	–	–	–	–
Energy Research & Dev Admin	390,686	24,862	–	297,523	3,472	6,839	57,990	–	–
Environmental Protection Agency	21,200	12,932	–	6,168	2,100	–	–	–	–
Federal Trade Commission	355	–	–	–	–	–	–	355	–
General Services Admin	65	–	–	–	–	–	–	–	65
Library of Congress	150	–	–	–	–	–	–	–	150
Natl Aeronautics & Space Admin	319,694	13,673	801	198,077	66,892	3,253	36,714	100	184
National Science Foundation	605,821	113,410	9,964	164,648	138,650	37,430	68,165	37,074	36,480
Off of Telecommunications Policy	190	58	–	–	–	–	–	132	–
Smithsonian Institution	30,569	12,977	–	5,125	2,377	–	–	10,090	–
Veterans Administration	9,300	7,823	1,152	–	–	–	–	–	325

Source: *Federal Funds* (see footnote Appendix D, Table C-30).

Appendix J

Table 1.—An analysis of Federal R&D funding by function, subfunction, and agency program, fiscal years 1969-78

[Dollars in millions]

Function, subfunction, and agency program	Actual								Estimates	
	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
Science and technology base, total	$513.4	$524.6	$523.8	$601.2	$604.7	$694.6	$781.6	$839.2	$952.6	$1,059.9
Basis for national physical measurement system (NBS) (Commerce)	16.4	18.0	14.6	15.6	15.8	18.1	18.9	20.2	23.0	21.3
Special foreign currency program (NBS) (Commerce)	—	—	—	—	—	—	—	—	.1	.2
Patent and Trademark Office (Commerce)	.4	.4	.6	.6	.6	.5	.5	.4	.4	.4
Library of Congress	1.8	1.9	2.5	2.3	2.6	2.2	2.6	3.0	3.1	3.4
High-energy physics (ERDA)	118.6	120.5	118.5	116.4	122.6	125.8	136.2	154.0	170.0	188.0
Nuclear physics (ERDA)	128.5	129.6	124.0	117.4	117.7	127.0	155.5	54.6	64.9	68.4
Basic energy sciences (ERDA)								112.9	128.9	147.1
Sustaining university program (NASA)	8.9	7.7	—	—	—	—	—	—	—	—
Materials processing in space (NASA)	—	—	—	—	—	4.3	6.5	8.3	12.6	21.3
Mathematical sciences research project support (NSF)	12.7	12.7	12.9	13.9	14.3	15.3	17.2	18.2	21.2	23.4
Computer research project support (NSF)	11.4	13.0	9.9	12.5	9.4	10.3	12.3	13.9	15.7	17.3
Physics research project support (NSF)	25.7	23.8	25.5	32.7	33.4	38.7	44.1	47.9	56.7	61.8
Chemistry research project support (NSF)	17.8	17.4	19.6	23.1	21.3	28.1	34.2	31.5	36.2	39.9
Engineering research project support (NSF)	16.0	16.7	14.1	25.1	25.0	29.6	35.8	37.6	41.7	44.5
Materials research project support (NSF)	7.8	7.7	11.1	33.3	31.9	37.5	45.5	48.5	53.9	58.8
Astronomy research project support (NSF)	6.8	5.8	6.7	7.8	8.2	9.8	10.0	10.4	12.9	14.6
Atmospheric sciences research project support (NSF)	8.2	7.9	9.4	11.5	11.5	12.9	14.4	15.2	19.1	20.3
Earth sciences research project support (NSF)	7.9	7.8	8.1	9.5	9.1	11.6	13.5	16.4	17.0	21.2
Oceanography research project support (NSF)	11.0	8.9	10.0	12.6	12.1	14.1	15.9	16.7	18.9	20.6
Physiology, cellular, and molecular biology research project support (NSF)	27.5	28.0	26.6	34.5	27.2	38.4	43.7	46.7	54.6	62.6
Behavioral and neural sciences research project support (NSF)	8.2	8.8	13.0	15.1	14.4	17.5	19.3	21.1	25.1	30.0
Environmental biology research project support (NSF)	7.0	8.6	8.5	10.3	17.6	22.9	27.2	28.6	32.6	35.7
Social sciences research project support (NSF)	10.8	10.9	13.0	16.6	16.7	19.1	18.8	20.0	22.9	25.5
Oceanographic facilities operations support (NSF)	8.6	7.4	8.2	9.6	10.0	14.6	16.3	15.9	18.5	17.8
Solar eclipse support (NSF)	—	—	—	.1	.7	—	—	.1	—	—
Ocean sediment coring program (NSF)	2.4	6.6	7.1	9.1	9.7	11.7	12.3	12.7	13.8	14.2
Science information activities (NSF)	6.4	7.0	7.0	7.5	9.4	7.9	5.4	6.1	5.3	5.3
National Astronomy and Ionosphere Center (NSF)	—	1.4	2.3	3.0	2.8	3.4	3.3	4.1	4.0	5.9
Kitt Peak National Observatory (NSF)	5.6	6.4	7.1	7.3	6.2	8.2	7.2	8.0	8.2	8.7
Cerro-Tololo Inter-American Observatory (NSF)	1.2	1.5	2.0	2.1	2.0	2.4	2.5	3.3	3.2	3.5
National Radio Astronomy Observatory (NSF)	7.3	5.1	6.8	6.5	6.1	7.5	5.8	5.7	6.5	9.7
National Center for Atmospheric Research (NSF)	10.4	11.2	14.0	17.2	14.3	18.4	18.2	19.2	20.3	23.9
Sacramento Peak Observatory (NSF)	—	—	—	—	—	—	—	—	.7	1.4

Table 1.—Continued

An analysis of Federal R&D funding by function, subfunction, and agency program, fiscal years 1969-78

Function, subfunction, and agency program	Actual								Estimates	
	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
Exploratory research and technology assessment (RANN) (NSF)	—	1.0	1.4	1.2	.7	1.2	1.3	1.5	1.5	2.2
Science Assessment, Policy, and Planning (NSF)	1.0	.7	1.3	1.8	3.6	6.4	10.2	7.9	5.3	5.3
Special foreign currency program (NSF)	—	—	1.0	1.9	3.5	4.4	2.2	3.2	3.3	3.9
Office of Science and Technology	1.8	1.9	2.0	2.0	—	—	—	—	—	—
Smithsonian Institution	14.8	18.2	15.1	21.3	24.0	24.7	24.8	25.7	30.6	32.1

Source: Division of Science Resources Studies, National Science Foundation

Appendix K

Table P-5.— Conduct of basic research by major departments and agencies (in millions of dollars)[1]

Department or agency	Obligations			Outlays		
	1977 actual	*1978 estimate*	*1979 estimate*	*1977 actual*	*1978 estimate*	*1979 estimate*
Health, Education, and Welfare	753	863	992	707	819	946
(National Institutes of Health)	(669)	(763)	(856)	(623)	(725)	(827)
National Science Foundation	625	688	755	582	653	696
National Aeronautics and Space Administration	414	468	520	437	474	516
Energy	389	433	468	373	417	458
Defense—military functions	294	321	364	274	293	338
Agriculture	201	245	262	188	228	228
Interior	129	158	164	125	156	161
Smithsonian	31	31	33	30	31	33
Commerce	23	27	31	23	27	31
Environmental Protection Agency	20	20	28	15	16	25
All other[2]	21	35	31	21	28	30
Total	2,900	3,288	3,647	2,776	3,143	3,462

[1] Amounts reported in this table are included in totals for conduct of R. & D.

[2] Includes the Departments of Justice, Labor, and State; the Veterans Administration, the Civil Service Commission, the Corps of Engineers, the Federal Trade Commission, the Tennessee Valley Authority, and the Library of Congress.

Source: *The Budget of the United States Government, Fiscal Year 1979, Special Analyses—(P) Research and Development* (GPO: Washington, 1978)

ABBREVIATIONS AND ACRONYMS*

AAEO — [Directorate for] Astronomical, Atmospheric, Earth, and Ocean Sciences (NSF)

AAF — Army Air Force

ABMA — Army Ballistic Missile Agency

ACDA — Arms Control and Disarmament Agency

ACPL — Applied Cloud Physics Laboratories (NASA)

ACTION — Independent U. S. agency embracing the Peace Corps, Volunteers in Service to America, and other volunteer service programs

ADAMHA — Alcohol, Drug Abuse, and Mental Health Administration (HEW)

AEC — Atomic Energy Commission

AFAPL — Air Force Aero Propulsion Laboratory

AFCRL — Air Force Cambridge Research Laboratories

AFOSR — Air Force Office of Scientific Research

AFRRI — Armed Forces Radiobiology Research Institute

AID — Agency for International Development (State)

AIDJEX — Arctic Ice Dynamics Joint Experiment

ARI — Army Research Institute

ARL — Aerospace Research Laboratory (Air Force)

ARPA — Advanced Research Projects Agency (now DARPA, DOD)

ARS — Agricultural Research Service (Agriculture)

ASPR — Armed Services Procurement Regulations

AST — [Division of] Astronomical Sciences (NSF)

AUA — Argonne Universities Association

AUI — Associated Universities, Incorporated

AURA — Association of Universities for Research in Astronomy

AWRM — [Division of] Atmospheric Water Resources Management (Bureau of Reclamation, Interior)

BAE — Bureau of American Ethnology (Smithsonian)

BAT — best available technology

BBS — [Directorate for] Biological, Behavioral, and Social Sciences (NSF)

BID — bureau, institute, or division (NIH)

BLS — Bureau of Labor Statistics (Labor)

BMS — Biological and Medical Sciences (now Biological, Behavioral, and Social Sciences of NSF)

BOMEX — Barbados oceanographic and meteorological experiment (GATE)

BP — before the present

BPR — Bureau of Public Roads (DOT)

BuENG — Bureau of Engineering (Navy)

BUMED — Bureau of Medicine and Surgery (Navy)

BuORD — Bureau of Ordnance (Navy)

CAA — Clean Air Act

CAORF — Computer-Aided Operations Research Facility (MarAd)

CAT — computerized axial tomography

CCN — cloud condensation nuclei

CDTT — [Ad Hoc] Committee on Domestic Technology Transfer (FCST)

CEA — Council of Economic Advisers

CEQ — Council on Environmental Quality

CFL — Committee on Federal Laboratories (FCST)

CG — Coast Guard

CGAR — Consultative Group on Agricultural Research

CGPP — Committee on Government Patent Policy (FCST)

CHESS — Community health environmental survey system (EPA)

*Only the more frequently mentioned or significant organizations, projects, facilities, and scientific and organizational terms mentioned in this report are included. Note that many organizations included no longer exist or their functions have been absorbed by new agencies.

CIGP	[Ad Hoc] Committee on the International Geodynamics Project (FCST)
CNO	Chief of Naval Operations
CNR	Chief of Naval Research
COM	Committee on Materials (FCST)
CRIS	Current Research Information System (Agriculture)
CRREL	Cold Regions Research and Engineering Laboratory (Army)
CSC	Civil Service Commission
CSRD	[Ad Hoc] Committee on Social Research and Development (FCST)
CSRS	Cooperative State Research Service (Agriculture)
CTIO	Cerro Tololo Inter-American Observatory
CW	continuous wave
CWRR	Committee on Water Resources Research (FCST)
CXAM	a type of radar
DARCOM	Army Materiel Development and Readiness Command
DARPA	Defense Advanced Research Projects Agency (DOD)
DDC	Defense Documentation Center
DDR&E	Director of Defense Research and Engineering
DHCC	dihydroxycholecalciferol (dihydroxyvitamin D_3)
DI	Department of the Interior
DMA	Division of Military Applications (ERDA)
DNA	Defense Nuclear Agency
DNA	deoxyribonucleic acid
DNL	Director of Navy Laboratories
DOA	Department of Agriculture (also USDA)
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
DPP	Division of Polar Programs (NSF)
DRG	Division of Research Grants (HEW)
DSDP	Deep Sea Drilling Program (NSF)
DST	Director of Science and Technology (Air Force)
EDA	Economic Development Administration (Commerce)
EEOC	Equal Employment Opportunity Commission
EES	Engineering Experiment Station (Navy)
EHAP	experimental housing allowance program (HUD)
EPA	Environmental Protection Agency
ERC's	Energy Research Centers (ERDA)
ERDA	Energy Research and Development Administration (now in DOE)
ERL	Environmental Research Laboratories (NOAA)
EROS	Earth Resources Observation System (USGS)
ERS	Economic Research Service (Agriculture)
ESSA	Environmental Science Services Administration
FAA	Federal Aviation Administration (DOT)
FCC	Federal Communications Commission
FCCSET	Federal Coordinating Council for Science, Engineering, and Technology
FCRC	Federal Contract Research Center
FCS	Farmer Cooperative Service (Agriculture)
FCST	Federal Council for Science and Technology (now FCCSET)
FCSTOC	FCST Operating Committee
FDA	Food and Drug Administration
FEA	Federal Energy Administration (now in DOE)
FERMILAB	Fermi National Accelerator Laboratory
FFRDC	Federally Funded Research and Development Center
FGGE	First GARP Global Experiment
FHA	Federal Highway Administration (DOT)
FHA	Federal Housing Administration (HUD)

FHLBB	Federal Home Loan Bank Board
FJSRL	Frank J. Seiler Research Laboratory (Air Force)
FPC	Federal Power Commission
FS	Forest Service (Agriculture)
FWPCA	Federal Water Pollution Control Act
FWS	Fish and Wildlife Service (Interior)
GARP	Global Atmospheric Research Program
GATE	GARP Atlantic Tropical Experiment
GFDL	Geophysical Fluid Dynamics Laboratory (NOAA)
GNP	gross national product
GOCO	government-owned/contractor-operated
GSA	General Services Administration
HAO	High Altitude Observatory
HDL	Harry Diamond Laboratories (Army)
HEAO	High Energy Astronomy Observatory
HEW	Department of Health, Education, and Welfare (or DHEW)
HSA	Health Services Administration (HEW)
HUD	Department of Housing and Urban Development
IARCC	Interagency Arctic Research Coordinating Committee (FCST)
IAT	Institute for Applied Technology (NBS)
IBS	Institute for Basic Standards (NBS)
ICAS	Interdepartmental Committee for Atmospheric Sciences (FCST)
ICASE	Institute for Computer Applications for Science and Engineering
ICBM	Intercontinental Ballistic Missile
ICCA	Interagency Coordinating Committee for Astronomy (FCST)
ICET	Interagency Committee on Excavation Technology (FCST)
ICMSE	Interagency Committee on Marine Science and Engineering (FCST)
ICSRD	Interdepartmental Committee on Scientific Research and Development
ICST	Institute for Computer Sciences and Technology (NBS)
IDA	Institute for Defense Analyses
IDL	Interdisciplinary Laboratories [program]
IDOE	International Decade of Ocean Exploration
IFYGL	International Field Year of the Great Lakes
IGY	International Geophysical Year
IMR	Institute for Materials Research (NBS)
IMS	International Magnetospheric Study
INR	Bureau of Intelligence and Research (State)
IR	infrared
ITFIMS	Interagency Task Force on Inadvertent Modification of Stratosphere (FCST)
ITS	Institute for Telecommunication Sciences (Office of Telecommunications)
JILA	Joint Institute for Laboratory Astrophysics
JOIDES	Joint Oceanographic Institutions for Deep Earth Sampling
JPL	Jet Propulsion Laboratory
JSC	Lyndon B. Johnson Space Center
KPNO	Kitt Peak National Observatory
LEAA	Law Enforcement Assistance Administration (Justice)
LINAC	linear accelerator
LMPD	Office of Labor-Management Policy Development (Labor)
LMSA	Labor-Management Services Administration (Labor)
LSI	Lunar Science Institute
MAPS	Management and Planning System (Agriculture)
MarAd	Maritime Administration (Commerce)
MIT	Massachusetts Institute of Technology
MODE	Mid-Ocean Dynamics Experiment
MONEX	monsoon experiment
MPE	[Directorate for] Mathematical and Physical Sciences and Engineering (NSF)
MRL	Materials Research Laboratory

MSC	Manned Spacecraft Center
MTRB	Maritime Transportation Research Board
MUMMERS	Manned-Unmanned Environmental Research Stations (Navy)
NACA	National Advisory Committee for Aeronautics
NACOA	National Advisory Committee on Oceans and Atmosphere
NAE	National Academy of Engineering
NAIC	National Astronomy and Ionosphere Center
NARL	U.S. Naval Aircraft Radio Laboratory
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NAWDEX	national water data exchange (U. S. Geological Survey)
NBS	National Bureau of Standards (Commerce)
NCAR	National Center for Atmospheric Research
NCER	National Council on Educational Research (NIE)
NCI	National Cancer Institute
NCIC	National Cartographic Information Center (U.S. Geological Survey)
NDE	nondestructive evaluation
NDRC	National Defense Research Committee
NEP	National Evaluation Program (NILECJ)
NEPA	National Environmental Policy Act
NFPCA	National Fire Prevention and Control Administration
NHTSA	National Highway Traffic Safety Administration (DOT)
NIAAA	National Institute on Alcohol Abuse and Alcoholism (ADAMHA)
NIAID	National Institute of Allergy and Infectious Disease (NIH)
NIAMDD	National Institute of Arthritis, Metabolism, and Digestive Diseases (NIH)
NIDA	National Institute on Drug Abuse (ADAMHA)
NIE	National Institute of Education (HEW)
NIH	National Institutes of Health (HEW)
NILECJ	National Institute of Law Enforcement and Criminal Justice (LEAA)
NIMH	National Institute of Mental Health (ADAMHA)
NINCDS	National Institute of Neurological and Communicative Disorders and Stroke (NIH)
NIOSH	National Institute for Occupational Safety and Health
NMFS	National Marine Fisheries Service (NOAA)
NML	National Magnet Laboratory
NMR	nuclear magnetic resonance
NNMC	National Naval Medical Center
NOAA	National Oceanic and Atmospheric Administration (Commerce)
NOL	Naval Ordnance Laboratory
NORDA	Naval Oceanographic Research and Development Activity
NORPAX	North Pacific Experiment
NP	neuropsychiatric
NPS	National Park Service (Interior)
NRAO	National Radio Astronomy Observatory
NRC	National Research Council
NRL	Naval Research Laboratory
NSB	National Science Board
NSF	National Science Foundation
NSPS	new source performance standards
NTIS	National Technical Information Service (Commerce)
OCS	outer continental shelf
ODTD	Office of Development, Testing, and Dissemination (NILECJ)
OES	Bureau of Oceans and International Environmental and Scientific Affairs (State)
OFS	Oceanographic Facilities and Support (NSF)
OHEF	Office of Health Ecological Effects (EPA)

O/I	output-input
OMB	Office of Management and Budget (Executive Office of the President)
ONR	Office of Naval Research
OPNAV	Office of the Chief of Naval Operations
OPP	Office of Pesticide Programs (EPA)
ORD	Office of Research and Development (EPA)
OSCP	Ocean Sediment Coring Program
OSHA	Occupational Safety and Health Administration (Labor)
OST	Office of the Secretary of Transportation (DOT)
OSTP	Office of Science and Technology Policy
OTS	Office of Toxic Substances (EPA)
OWPS	Office of Water Planning and Standards (EPA)
OWRT	Office of Water Research and Technology (Interior)
PHA's	Public Housing Authorities
PHS	Public Health Service
POLYMODE	Joint U.S./U.S.S.R. Mid-Ocean Dynamics Experiment
PPI	[Office of the Asst. Secretary for] Policy Plans and International Affairs (DOT)
PSAC	President's Science Advisory Committee
RANN	Research Applied to National Needs (NSF)
RAP	research agreements program (NI-LECJ)
RATE	Research on Arctic Tundra Environments
RDAC	Research, Development, and Acquisition Council (Army)
R&D	research and development
RD&D	research, development, and demonstration
RFP	request for proposal
RISP	Ross Ice Shelf Project
RNA	ribonucleic acid
RTOP	research and technology objectives and plans (NASA)
SAES	State Agricultural Experiment Stations
SAO	Smithsonian Astrophysical Observatory
SBA	Small Business Administration
SEAN	Scientific Event Alert Network
SFRO	State Forestry Research Organizations
SIC	Standard Industrial Classification Manual Code
SLAC	Stanford Linear Accelerator Center
SPO	Sacramento Peak Observatory
SRC	[Wisconsin] Synchrotron Radiation Center
SRS	Statistical Reporting Service (Agriculture)
SSIE	Smithsonian Science Information Exchange
SSRP	Stanford Synchrotron Radiation Project
S&T	science and technology
STAR	Scientific Technical Aerospace Reports (NASA)
STIA	[Directorate for] Scientific, Technological, and International Affairs (NSF)
STOG	Science and Technology Objectives Guide (Army)
STPO	Science and Technology Policy Office (NSF)
STRATCOM	stratospheric composition program (Army)
SYSCOM	system command
TVA	Tennessee Valley Authority
UCAR	University Corporation for Atmospheric Research
UMTA	Urban Mass Transit Administration (DOT)
UNOLS	University-National Oceanographic Laboratory System
URA	Universities Research Association, Inc.
USARP	United States Antarctic Research Program
USCG	U.S. Coast Guard
USDA	U.S. Department of Agriculture (also DOA)

USDRE	[Office of the] Under Secretary of Defense for Research and Engineering (DOD)
USGS	U.S. Geological Survey
USMC	U.S. Marine Corps
USRA	Universities Space Research Association
UV	ultraviolet
VA	Veterans Administration
VLA	Very Large Array
VLBI	very long baseline interferometry
WHOI	Woods Hole Oceanographic Institution
WMO	World Meteorological Organization
WPL	Wave Propagation Laboratory (NOAA)
WSMR	White Sands Missile Range (Army)

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